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TECTONIC EVOLUTION AND STRUCTURAL STYLE OF THE BROOKS RANGE, ALASKA: AN ILLUSTRATED SUMMARY

C.G. MULL[1]

ABSTRACT

The Brooks Range and Arctic Slope of northern Alaska comprise the Arctic Alaska plate, a small continental lithospheric plate bounded on the north by an extensional (Atlantic style) plate margin and bounded on the south by a compressional margin. Evidence favors the hypothesis of counterclockwise rotation of this block in the Early Cretaceous to form the Canada basin of the Arctic Ocean. Deformation along the compressional margin of the plate resulted in formation of a major orogenic belt with obduction of ophiolitic rocks over the leading edge of the continental rocks of the plate and over 580 km (360 mi) of crustal shortening in at least part of the belt. An asymmetrical foredeep north of the thrust belt is filled with Neocomian to Albian lithic flysch and molasse derived from the imbricated sedimentary and mafic-ultramafic igneous terranes.

Middle and Late Cretaceous isostatic rebound of the deeply depressed sialic crust resulted in several kilometers of vertical uplift in the core zone, which breached the stack of allochthons. Parautochthonous Paleozoic metasedimentary and granitic rocks are exposed in the regional anticlinorium which forms the core of the range. To the north, the allochthons forming the frontal ranges, the De Long and Endicott Mountains, were extensively folded and refaulted. At the mountain front autochthonous Triassic and older sedimentary rocks are at depths of over 8 km (26,000 ft) beneath Cretaceous flysch and the folded leading edges of the allochthons. In the northeastern Brooks Range, autochthonous rocks are exposed on the flanks of a regional Late Cretaceous and Tertiary uplift centered in the Romanzof Mountains. The structural style of the northeastern Brooks Range is dominantly vertical basement-involved uplift and no allochthonous rocks are present at the mountain front.

An Albian and Late Cretaceous molassoid wedge derived from the south and west filled the successor basin north of the mountains and prograded north and east over the rifted northern margin of the Arctic Alaska plate. On the northeastern Arctic Slope, the distal end of this wedge is Tertiary in age. This clastic wedge is deformed by décollement that dies out northward from the mountain front; the zone of detachment is in incompetent Albian shale except in the northeast, where younger incompetent shale horizons probably form the zone of detachment.

Although the Brooks Range is the apparent northern extension of the western North American Cordilleran belt, its structural style is markedly different than the style of the frontal belt of the Canadian Rockies and Wyoming-Idaho thrust belts. Hydrocarbon potential of this belt in northern Alaska is probably limited by the extreme complexity of deformation along the De Long and Endicott Mountains front and by limited potential reservoir rocks along the northeastern Brooks Range mountain front. The best hydrocarbon potential in northern Alaska is along the northern margin of the Arctic Alaska plate, where Cretaceous and Tertiary rocks prograde over and truncate the rifted plate margin. Along this margin, offshore lands in the Beaufort Sea, both east and west of Prudhoe Bay, and along the coastal plain in the Arctic National Wildlife Refuge remain as the major exploration frontier of northern Alaska.

INTRODUCTION

This paper is a summary of an invited paper titled: "Evolution of the Brooks Range Thrust Belt and Arctic Slope" presented at the symposium "World-wide Thrust Belt and Foreland Basin Exploration" held at the 1980 AAPG annual convention in Denver. Documentation of the details of the stratigraphic and structural history of northern Alaska is beyond the scope of this paper, which is intended to illustrate the basic structural style of the Brooks Range and some of its critical localities. For discussions of the details of northern Alaskan geology the reader is referred to papers by Brosgé and others (1962); Brosgé and Tailleur (1971); Tailleur and Brosgé (1970); Reiser (1970); Detterman and others (1975); Armstrong (1974); Armstrong and Mamet (1974); Armstrong and Dutro (1970); Bird and Jordan (1977); Molenaar (in press); Martin (1970), and many other references cited in reference lists in the papers above.

Included in this paper is a generalized geologic map of the Brooks Range and Arctic Slope and four generalized regional cross sections. Photographic illustrations documenting critical relationships accompany the cross sections and map. The location of each photograph is plotted on an index map of northern Alaska (Fig. 1); the approximate location can be found by reference to the quadrangle name given with each photograph. Many of the major geographic names are given on the index map, but the reader interested in greater detail must refer to the individual 1:250,000 quadrangle maps obtainable from the U.S. Geological Survey. An accompanying Landsat mosaic image of northern Alaska (Fig. 2) conveys an overall view of the Brooks Range and Arctic Slope.

GENERALIZED GEOLOGY

The generalized geology of northern Alaska is illustrated in Figure 3. The Brooks Range is divided into four major terranes containing characteristic rock types generally deformed in a characteristic regional structural style. On the south a narrow belt of discontinuously exposed mafic igneous rocks (m-um), dominantly altered pillow basalt, forms the southern flank of the Brooks Range. Using the definition of the 1972 GSA Penrose Ophiolite Conference (Geotimes, December, 1972) these rocks can be considered part of a dismembered ophiolite. These rocks have regional south dip and are in thrust contact with a metamorphic and igneous terrane in the Baird, Schwatka, and south-

Regional tectonic interpretations presented in this paper result from a number of years of personal reconnaissance field studies in the Brooks Range and Arctic Slope while employed by Richfield Oil Corp. (Atlantic Richfield Co.), Exxon Co. USA, U.S. Geological Survey, and Alaska Division of Geological and Geophysical Surveys. The interpretations benefited from numerous discussions and flaming arm waving on the outcrop, in the office, and over the telephone with G.H. Pessel, I.L. Tailleur, H.S. Sonneman, H.E. Repp, G.W. Newman, D.H. Roeder, and J.T. Dillon. These geologists contributed field observations, interpretations, and concepts but do not necessarily concur with interpretations presented here. In addition, I would like to acknowledge published reports and maps by members of the U.S. Geological Survey including, W.P. Brosgé, H.N. Reiser, J.T. Dutro Jr., R.L. Detterman, M.D. Mangus, R.M. Chapman, E.G. Sable, W.W. Patton, Jr., D.F. Barnes, A.K. Armstrong, K.J. Bird, S.W. Nelson, D. Grybeck, C.F. Mayfield, I. Ellersieck, and C.M. Molenaar. Studies by these geologists and others provided mapping and stratigraphic control in many areas of the Brooks Range and Arctic Slope.

[1] Alaska Division of Geological and Geophysical Surveys, Pouch 7-028, Anchorage, Alaska 99501

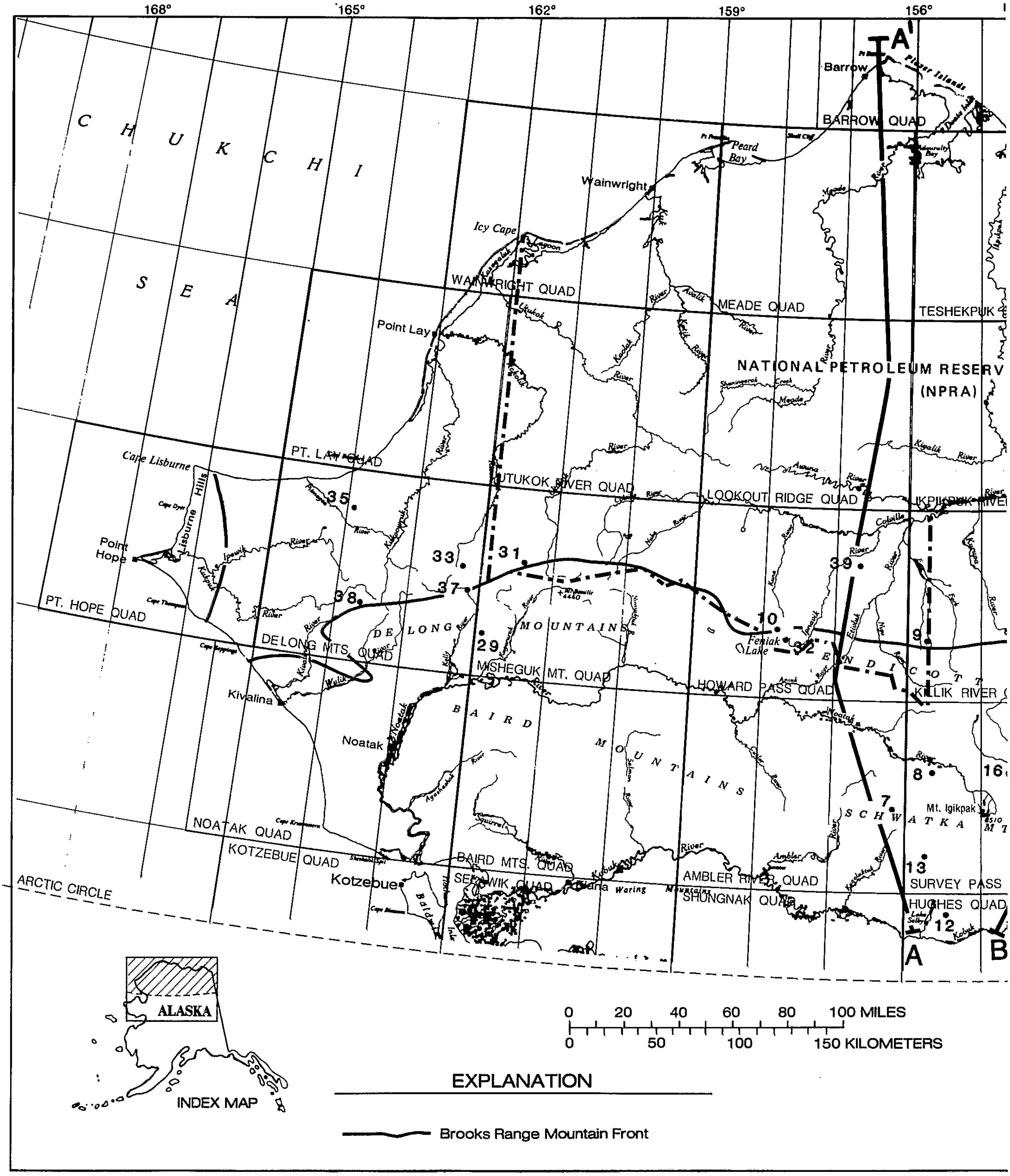
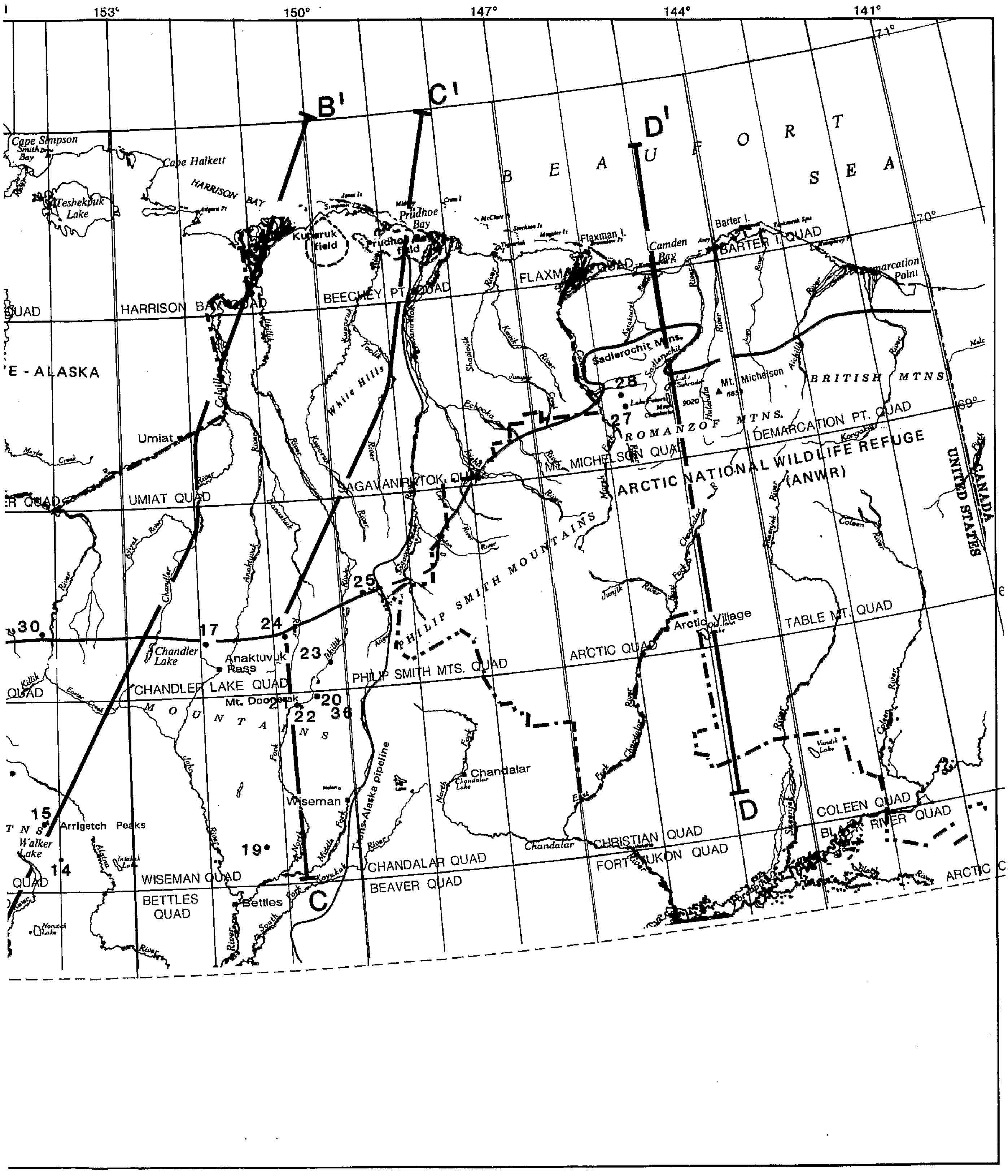


Figure 1. Index map of northern Alaska.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150°
147°
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71°
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69°
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C
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BEAUFORT SEA
Cape Simpson
Smith Bay
Cape Halkett
HARRISON BAY
Teshekpuk Lake
Kuparuk field
Prudhoe field
Prudhoe Bay
Flaxman I.
Camden Bay
Barter I.
BARTER I. QUAD
Demarcation Point
FLAXMAN I. QUAD
BEECHEY PT. QUAD
HARRISON BAY QUAD
QUAD
E - ALASKA
White Hills
Sadlerochit Mtns.
Mt. Michelson
BRITISH MTNS
ROMANZOF MTNS.
DEMARCATION PT. QUAD
MT. MICHELSON QUAD
ARCTIC NATIONAL WILDLIFE REFUGE (ANWR)
UNITED STATES
CANADA
Umiat
UMIAT QUAD
SAGAVANIRKTOK QUAD
PHILIP SMITH MOUNTAINS
TABLE MT. QUAD
Arctic Village
ARCTIC QUAD
PHILIP SMITH MTS. QUAD
Chandler Lake
Anaktuvuk Pass
CHANDLER LAKE QUAD
Mt. Doonerak
MOUNTAINS
Chandalar
Wiseman
Trans-Alaska pipeline
Arrigetch Peaks
Walker Lake
WISEMAN QUAD
BETTLES QUAD
Bettles
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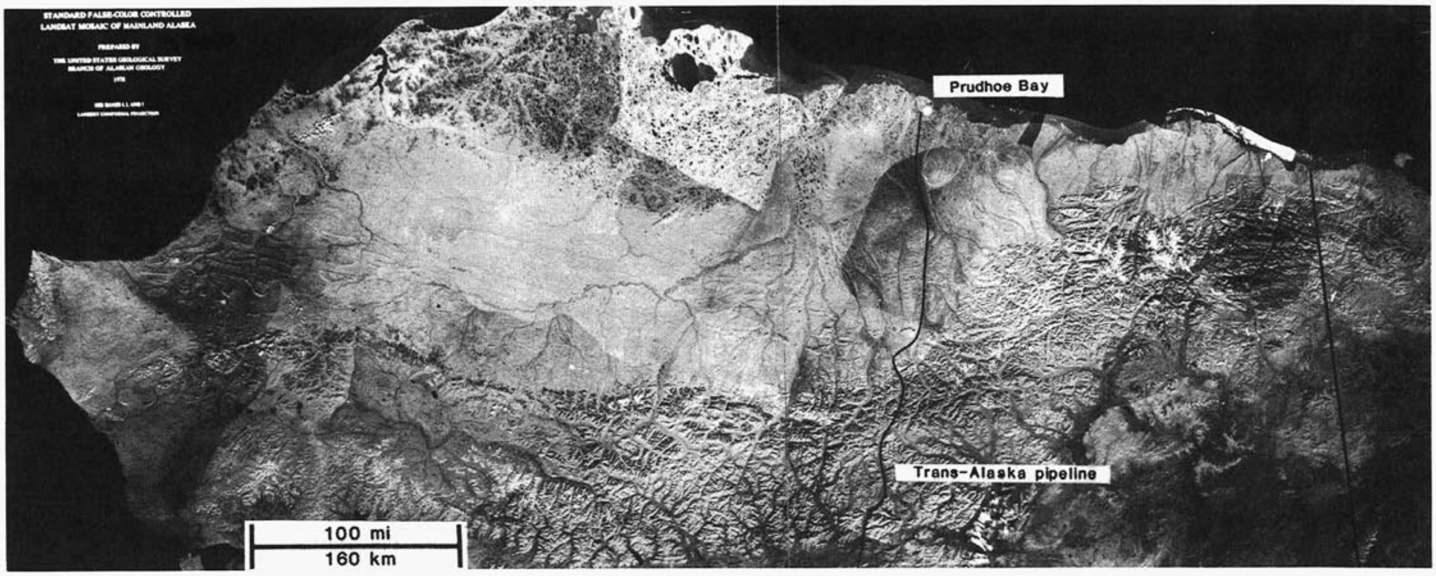


Figure 2. Mosaic Landsat image of Brooks Range and Arctic Slope. See Figure 1 for major geographic names. Mosaic by U.S. Geological Survey.

ern Endicott Mountains. This terrane consists of a belt of schist on the south, composed of metasedimentary and metavolcanic rocks of Precambrian to Middle Paleozoic age. Intense deformation characterizes the schist belt, with metamorphic grades ranging up to blue schist. The schist belt and northern belt of dominantly Middle Devonian and older limestone and phyllite (mD and IPz-pC) are exposed in a regional east-west trending anticlinorium containing a series of granitic plutons. These metamorphic and igneous rocks form the core zone of the Brooks Range and in their response to the Mesozoic orogeny that formed the present range, seem to be autochthonous or parautochthonous. South of the trend of plutons regional dip of the metamorphic complex is to the south, while north of the plutons regional dips are to the north.

North of the metamorphic belt is a belt of intensely thrust faulted sedimentary and minor mafic igneous rocks (D-$\bar{T}_R$) dominantly of Late Devonian to Triassic age, although some Middle Devonian rocks are present. The allochthons are mostly unmetamorphosed although the southern edge of the belt has some rocks of greenschist metamorphic grade. A number of distinctive major allochthons have been mapped and named throughout the De Long and Endicott Mountains. Each major allochthon contains a distinctive stratigraphic sequence that in most cases can be readily distinguished from the stratigraphic sequence of the overlying or underlying allochthons. Except on the uppermost ophiolitic allochthon crystalline basement rock is not present on the allochthons. Palinspastic restoration of the allochthons in the De Long Mountains documents crustal shortening of over 500 km (310 mi); eastward into the Endicott Mountains the magnitude of shortening seems to decrease. Juxtaposition of allochthonous facies was first recognized by Tailleur and others (1966); the allochthons have been subsequently documented and discussed more fully by Martin (1970), Ellersieck (1979), Tailleur and Brosgé (1970), and Mull (1979, and in preparation).

At the top of the stack of allochthons in the De Long and western Endicott Mountains is a series of isolated klippen preserved in regional synclines and composed of layered mafic and ultramafic igneous rocks consisting dominantly of pillow basalt, olivine gabbro, and dunite. These rocks constitute a dismembered ophiolite as defined by the 1972 Penrose Conference. In the western Brooks Range these rocks have been described by Roeder and Mull (1978), Patton and others (1977), Frank and Zimmerman (1982), Zimmerman and Soustek (1979), Zimmerman and Frank (1982), and most recently by Nelson and Nelson (1982).

In klippen in which basalt, gabbro, and dunite are all present, without exception the basalt is present at the base of the sequence and is overlain by a thrust sheet of dunite and overlying intertonguing olivine gabbro. No basalt is preserved overlying dunite or gabbro in any of the complexes. Cumulate textures predominate in the gabbro and dunite; tectonite fabrics are not abundant. Prominent layering shows that most of the ophiolitic complexes are folded into broad synforms with smaller scale folds superimposed in some places. Although the idealized ophiolite sequence is partially inverted, the rocks are not structurally overturned. The layering permits estimation of up to 7 km (23,000 ft) of dunite and gabbro preserved on at least one of the complexes. Palinspastic unstacking of the ophiolitic complexes indicates that the basalt and gabbro-dunite sheets were derived from discrete separate terranes that may have been adjacent to each other but were not vertically stacked prior to thrust faulting.

Regional dip of the southern edge of the terrane of allochthons is to the north, but collectively the allochthons of the western and central Brooks Range have been folded into a number of regional anticlinoria and synclinoria. In many places superimposed upon this regional structural style is intense intra-allochthon deformation, with numerous thrust faults and associated recumbent folds. This superimposed deformation within the allochthons is relatively small scale when viewed in the context of the overall scale of crustal shortening indicated by the major inter-allochthon relationships. With only a few exceptions, at the northern mountain front in the De Long and Endicott Mountains, the northernmost exposures of the allochthons dip northward beneath the Cretaceous rocks of the Arctic Slope.

The northeastern Brooks Range (M-$\bar{T}_R$ and IPz-pC) consists of autochthonous sedimentary rocks of Mississippian through Triassic age. These rocks overlie a major angular unconformity that truncates more highly deformed Early Paleozoic to Precambrian(?) metamorphic rocks exposed in the cores of sev-

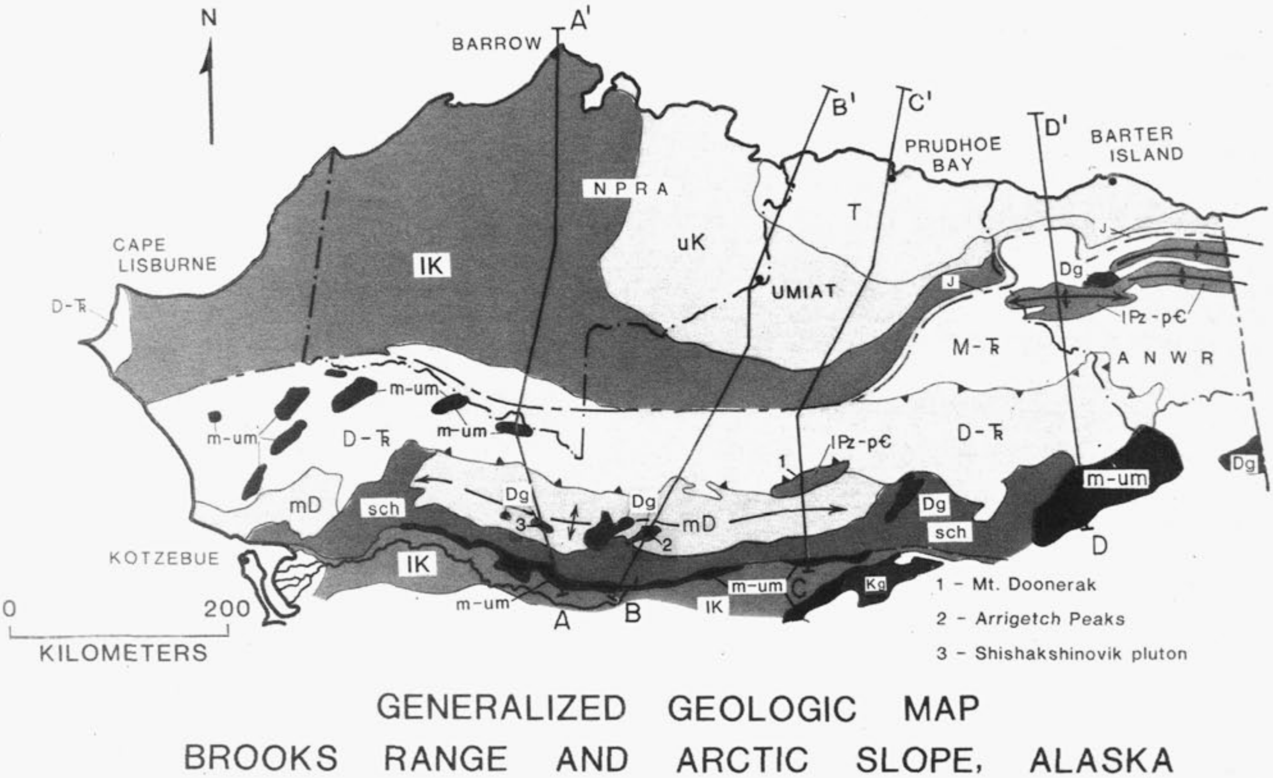


Figure 3. **Generalized geologic map of Brooks Range and Arctic Slope, Alaska. T - Tertiary; uK - Upper Cretaceous; IK - Lower Cretaceous; J - Jurassic; M - TR - Mississippian to Upper Triassic, autochthonous; D - TR - Upper Devonian to Upper Triassic, *allochthonous*; mD - Middle Devonian to Silurian; parauthochthonous; IPz - pC - Lower Paleozoic to Precambrian includes M - TR in Mt. Doonerak area; Kg - Cretaceous granite; Dg - Devonian granitic rocks, includes M-TR in Shishakshinovik pluton area; sch - middle Paleozoic to Precambrian(?) schist, parauthochthonous(?); m - um - Devonian to Triassic mafic to ultramafic rocks. NPRA - National Petroleum Reserve, Alaska; ANWR - Arctic National Wildlife Refuge.**

eral regional anticlinoria. The pre-Mississippian basement rocks of this area were apparently deformed by thrust faulting during the Middle Paleozoic, but were not telescoped during the Mesozoic Brooks Range orogeny. The Mississippian and younger rocks on the flanks of the breached anticlinoria are broken by high-angle reverse faults and associated folds. However, thrust faults are of limited magnitude and probably represent small-scale gravitational gliding off the flanks of the anticlinoria. Middle Paleozoic and younger allochthonous rocks characteristic of the central and western Brooks Range are not present at the mountain front in the northeastern Brooks Range.

North of the mountains, the foothills of the Brooks Range are underlain by a deltaic wedge of Albian to Tertiary age rocks that were derived from the Brooks Range and prograded northward and eastward. This clastic wedge is deformed into a series of long linear east-west trending breached anticlines and broad synclines. In outcrop, the breached anticlines are invariably cored by tightly crumpled shales; seismic data indicate a major décollement, with detachment dominantly in a thick zone of relatively incompetent Albian shale. Fold amplitudes die out northward from the mountain front so that the beds underlying the northern foothills and Arctic coastal plain are little deformed. Beds underlying the décollement zone are little deformed and generally dip gently southward toward the mountain front.

Regional gravity of northern Alaska is illustrated in Figure 4. Gravity data by Barnes (1977) show that a major gravity low underlies the Brooks Range. In the western and central Brooks Range, the gravity low underlies the southern part of the belt of major allochthons that form the frontal ranges. The gravity low does not coincide with the granitic core of the range. In the eastern Brooks Range, the axis of the gravity low is north of the present limit of the allochthons and coincides with the core of the range. A pronounced gravity high coincides with the Shublik and Sadlerochit Mountains at the north edge of the range in the Arctic National Wildlife Refuge. The structural style and deformational history of the northeastern Brooks Range differs from that of the central and western Brooks Range, and these fundamental differences are apparently reflected in the relationship of the gravity field to the surface geology. The differences in structural style and history are discussed in a later section of this paper.

AUTOCHTHONOUS VERSUS ALLOCHTHONOUS FACIES

The distinction and recognition of allochthonous versus autochthonous pre-Jurassic stratigraphic sequences is critical to the understanding of the fundamental structural style of the Brooks Range. These generalized sequences are illustrated in Figure 5.

The basic stratigraphic sequence of the subsurface of the

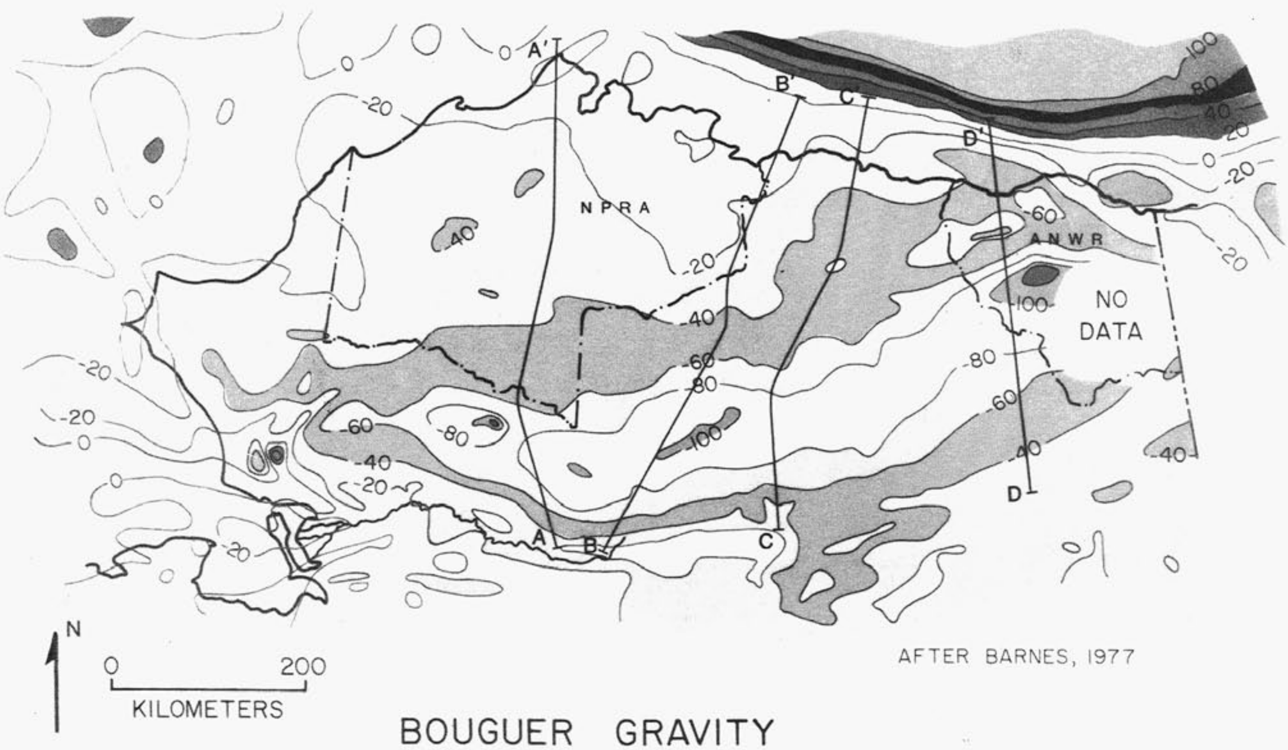


Figure 4. Generalized Bouguer gravity map of northern Alaska. Modified from Barnes, (1977). Contour interval — 20 milligals.

Arctic Slope consists of Mississippian and younger platform sediments overlying a major regional angular unconformity that truncates early Paleozoic and possibly Precambrian metasediments and at least one granitic pluton. Except where absent by truncation or nondeposition this sequence has been penetrated in every well drilled to basement on the Arctic Slope. Specific details of this autochthonous subsurface sequence are given by Morgridge and Smith (1972), Rickwood (1970), Jones and Spears (1976). Typical of the sequence is the section penetrated in Prudhoe Bay State #1, consisting of basal Mississippian Kekiktuk conglomerate and sandstone, Mississippian Kayak Shale, Mississippian to Early Pennsylvanian Lisburne Group limestone and dolomite, Permian to Lower Triassic Sadlerochit Group sandstone, conglomerate, and shale, and Upper Triassic Shublik Formation capped by Sag River Sandstone. A similar stratigraphic sequence is exposed throughout the northeastern Brooks Range and overlies a regional unconformity at the base of the Mississippian. The characteristics of this sequence are described by Reiser (1970) and mapped by Reiser and others (1971). In most areas, both in the subsurface and in surface outcrops, the autochthonous Mississippian and younger sequence ranges up to about 1500 meters (4500 ft) in thickness.

In contrast to the stratigraphic sequence of the northeastern Brooks Range and Arctic Slope subsurface is the sequence exposed in the Endicott Mountains of the central Brooks Range. The Endicott Mountains allochthon consists of several thousand meters of a thick deltaic wedge of Late Devonian Kanayut Conglomerate and Hunt Fork Shale conformably overlain by Mississippian Kayak Shale, Mississippian Lisburne Group limestone, dolomite, and chert, and Permian to Triassic shale, siliceous shale, chert, and silicified limestone of the Siksikpuk and Otuk Formations of the Etivluk Group. In addition, barite nodules are a common constituent of the Siksikpuk Formation. The major differences between this stratigraphic sequence and the autochthonous complex of the subsurface Arctic Slope and northeastern Brooks Range is the presence of the thick Upper Devonian clastic wedge, absence of a basal Mississippian unconformity, and the siliceous and barite-bearing nature of the Permian and Triassic sections.

Mississippian facies on the allochthons of the De Long and western Endicott Mountains are variable, the Lisburne Group in some areas consists entirely of black shale and/or chert. The Ipnavik River allochthon contains a Mississippian shale-chert-limestone facies with numerous diabase sills; on the Nuka Ridge allochthon the Mississippian consists of arkosic limestone, limy arkose, quartzite and sandstone. On these allochthons, the Permian and Triassic section has varying amounts of siliceous shale and silicified mudstone. On the north flank of the Schwatka Mountains, the Kugrak allochthon consists of a thick section of Middle Devonian Skajit Limestone unconformably overlain by Mississippian sandstone, conglomerate, shale, and minor limestone.

STRUCTURAL STYLE

SECTIONS

Four generalized regional cross sections illustrate the structural style of the Brooks Range and document critical outcrops that control the interpretation of the allochthonous re-

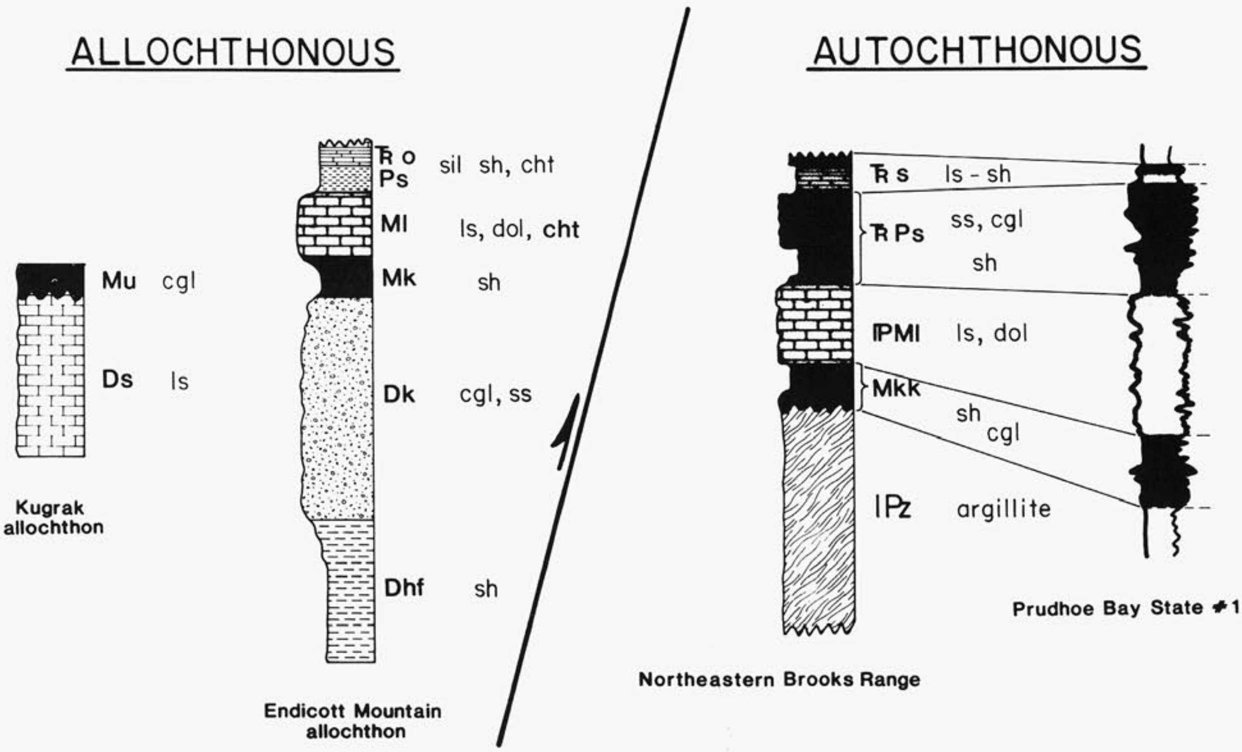


Figure 5. Typical Brooks Range autochthonous and allochthonous stratigraphic sequences.

Allochthonous sequences
- **Ŧ̶Ro — Triassic Otuk Formation** } **Etivluk Group**
- **Ps — Permian Siksikpuk Formation**
- **Ml — Mississippian Lisburne Group**
- **Mk — Mississippian Kayak Shale**
- **Mu — Mississippian unnamed sandstone**
- **Dk — Upper Devonian Kanayut Conglomerate**
- **Dhf — Upper Devonian Hunt Fork Shale**

Autochthonous sequences
- **Ŧ̶Rs — Triassic Shublik Formation includes Sag River sandstone — Karen Creek Sandstone at top**
- **Ŧ̶RPs — Triassic to Permian Sadlerochit Group**
- **IPMl — Pennsylvanian to Mississippian Lisburne Group**
- **Mkk — Mississippian Kayak Shale and Kekiktuk Conglomerate**
- **lPz — Lower Paleozoic argillite**

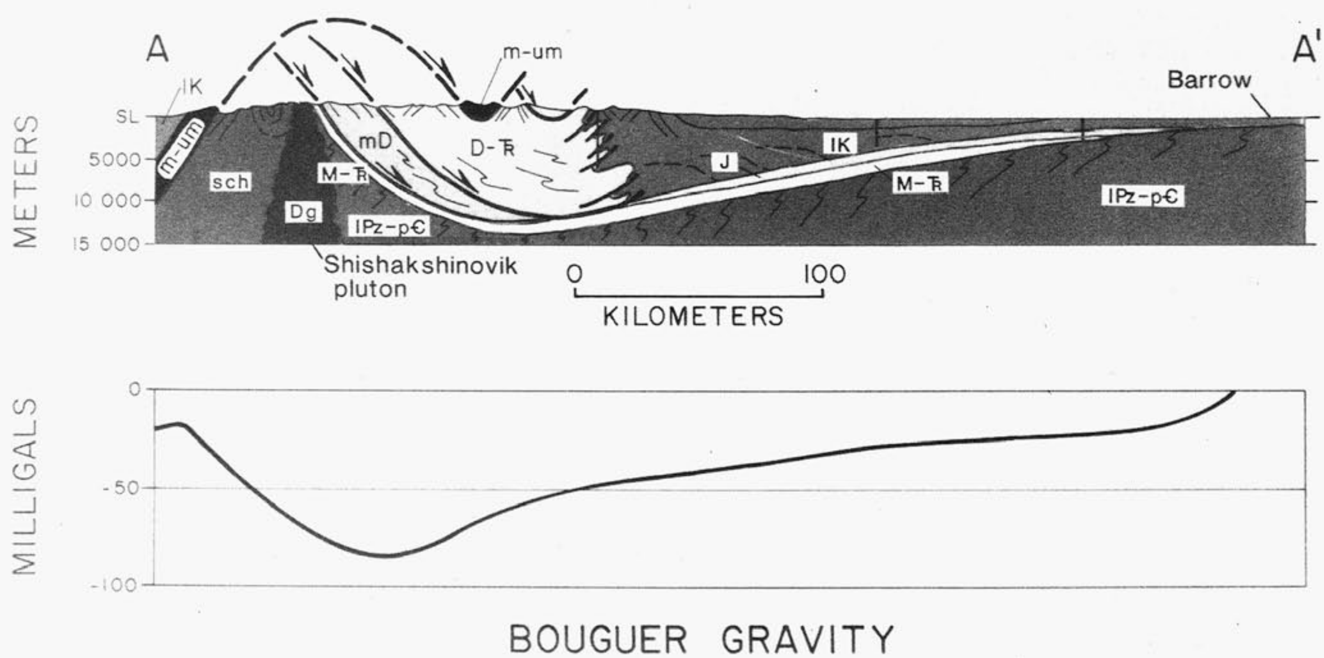


Figure 6. Section A-A′ from Angayucham Mountains across Shishakshinovik pluton and Howard Pass to Barrow. See Figure 3 for explanation of symbols.

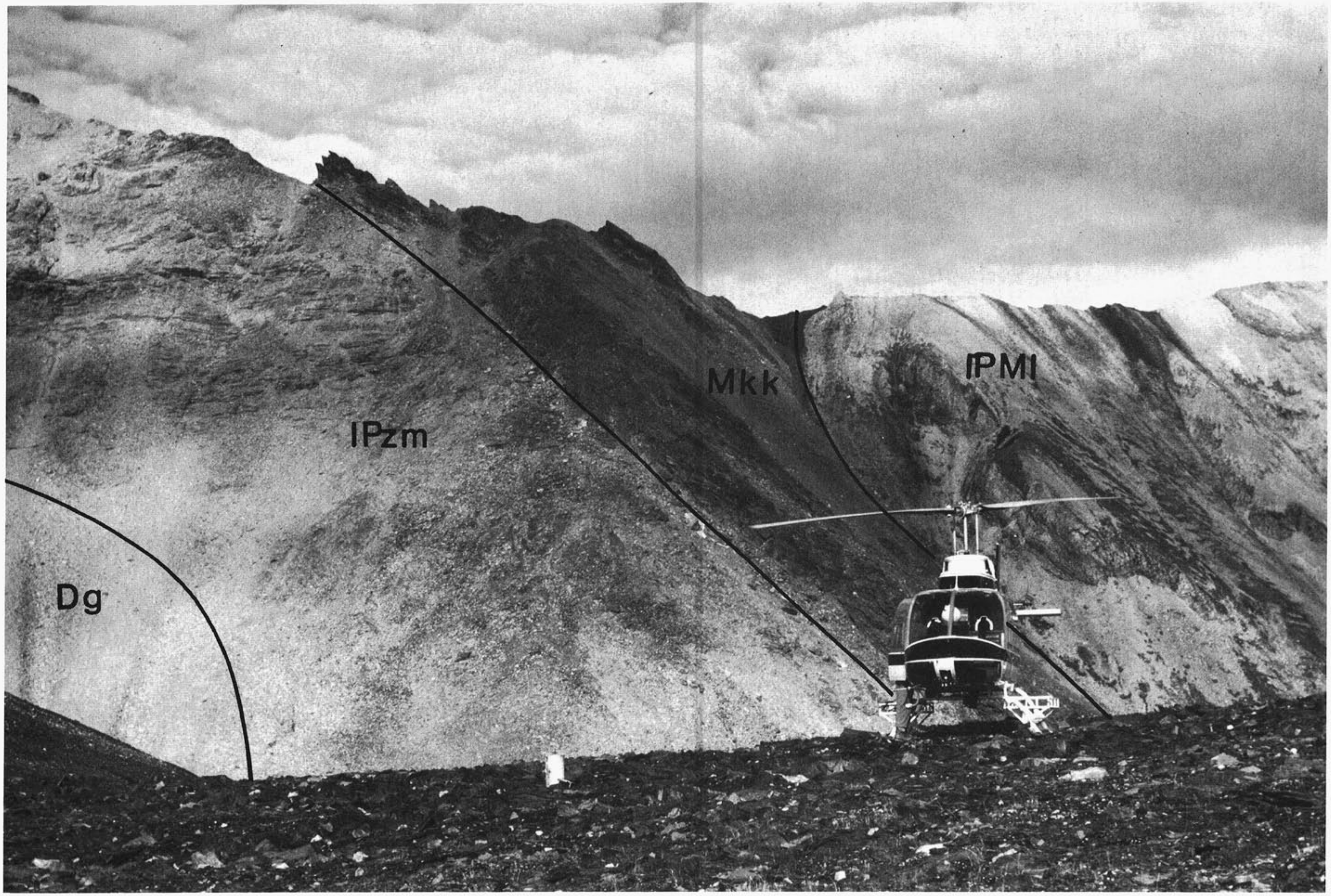


Figure 7. Westward view of basal Mississippian angular unconformity on north flank of Shishakshinovik pluton, Ambler River quadrangle. Early Paleozoic metaquartzite (IPzm) and Shishakshinovik granite (Dg) are overlain at an angular unconformity by 45° north-dipping Kekiktuk Conglomerate and Kayak Shale (Mkk), Lisburne Group dolomite and limestone (IPMl), and Sadlerochit Group sandstone (out of view).

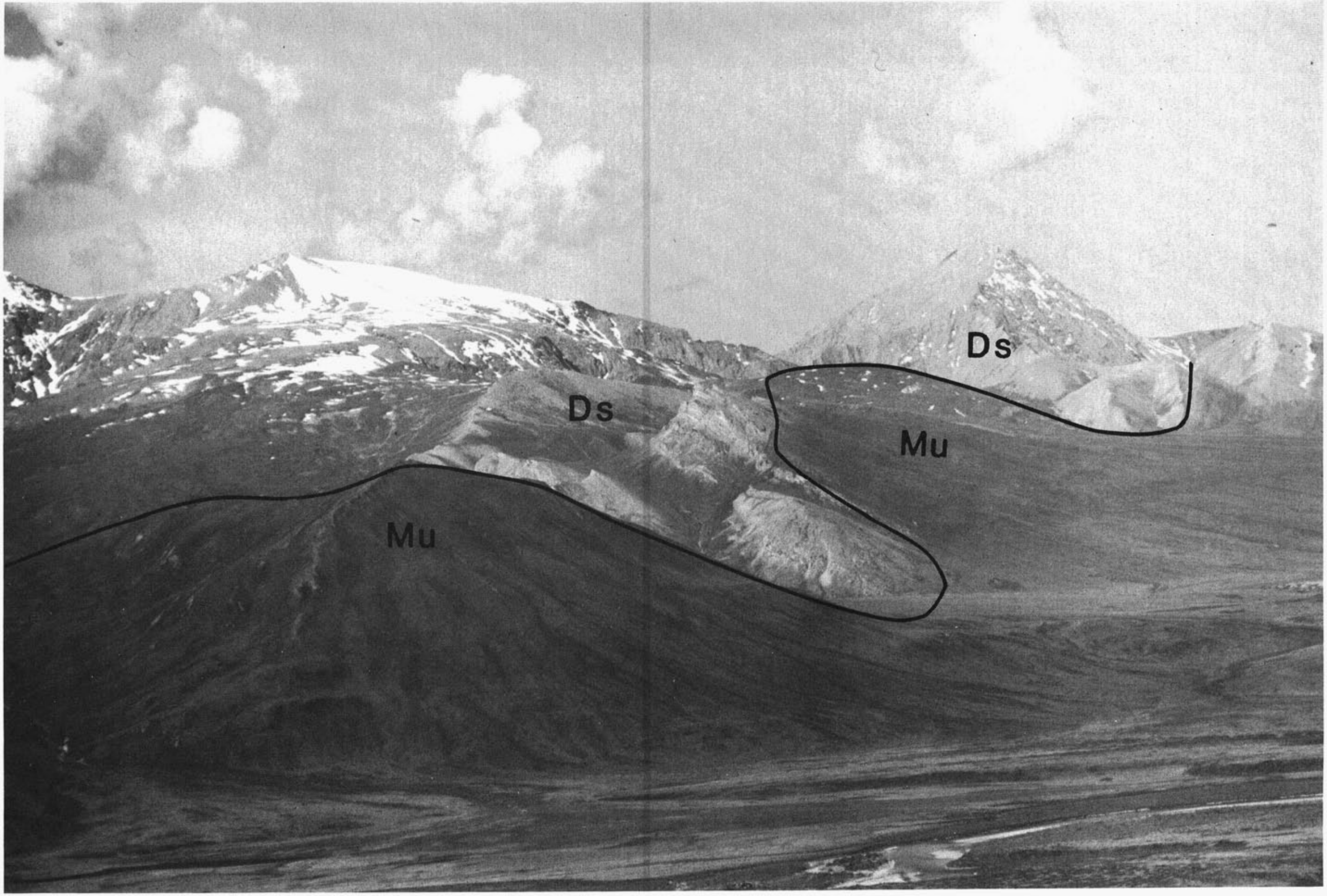


Figure 8. **Southwestward view of north flank of Schwatka Mountains, upper Noatak River, western Survey Pass quadrangle. Skajit Limestone (Ds) and disconformably overlying Mississippian quartzite and conglomerate (Mu) of the Kugrak allochthon dip north into Noatak River valley. Sole fault of the overlying Endicott Mountains allochthon is buried beneath alluvium of Noatak River valley, but is exposed a short distance to the west of view. Basal part of the Upper Devonian Hunt Fork Shale on the Endicott Mountains allochthon is discontinuously exposed along the river valley.**

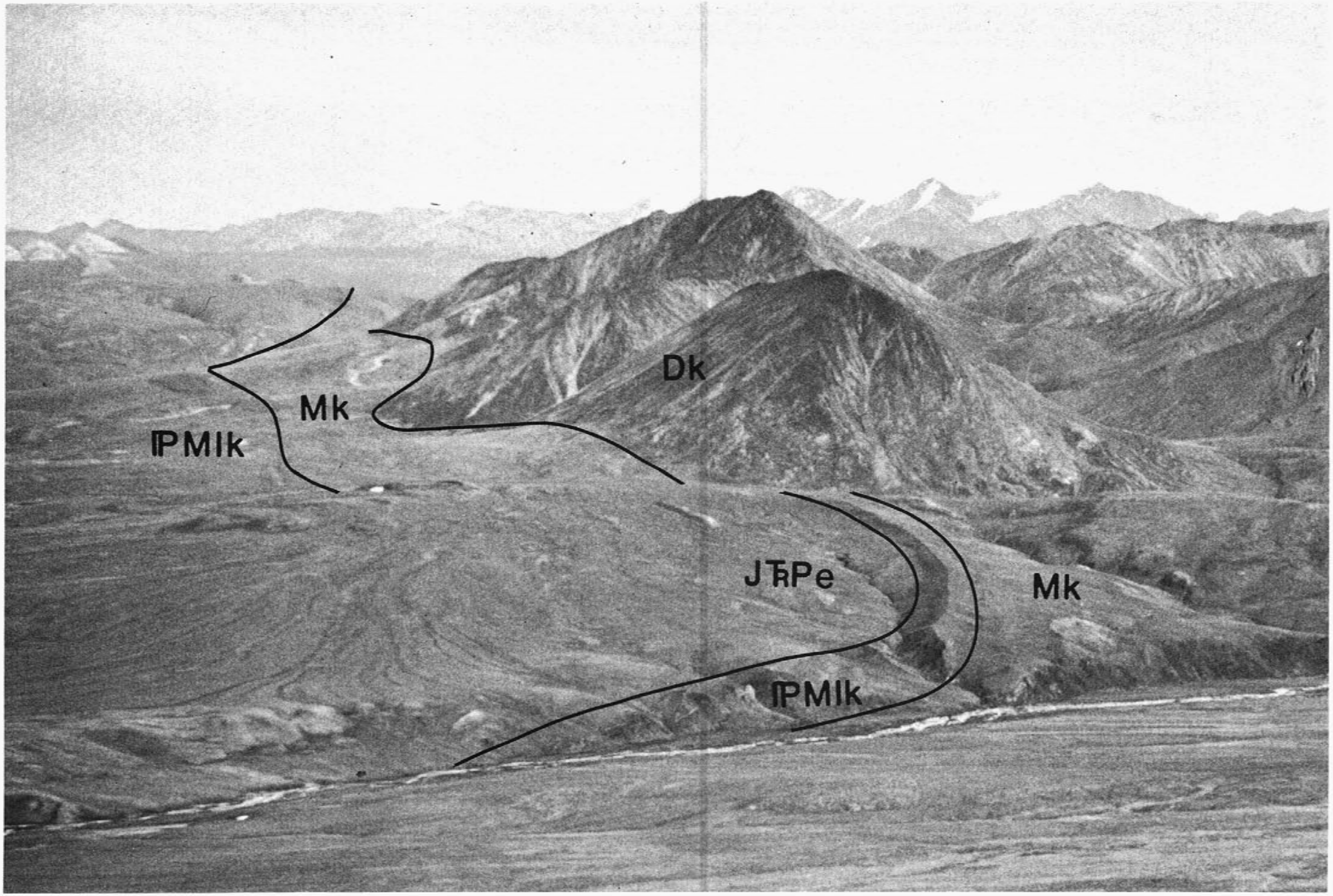


Figure 9. Southeastward view of north flank of Endicott Mountains near Otuk Creek, western Howard Pass quadrangle. Etivluk Group (J TR Pe), Kuna formation of Lisburne Group (ℙMlk), and Kayak Shale (Mk) conformably overlie north dipping Kanayut Conglomerate (Dk) on Endicott Mountains allochthon.

Figure 10. Southwestward view of western Endicott Mountains front at headwaters of Kuna River, Howard Pass quadrangle. Mississippian Kayak Shale (Mk) and the Upper Devonian Kanayut Conglomerate (Dk) on the Endicott Mountains allochthon dip 30° N to 70° S overturned.

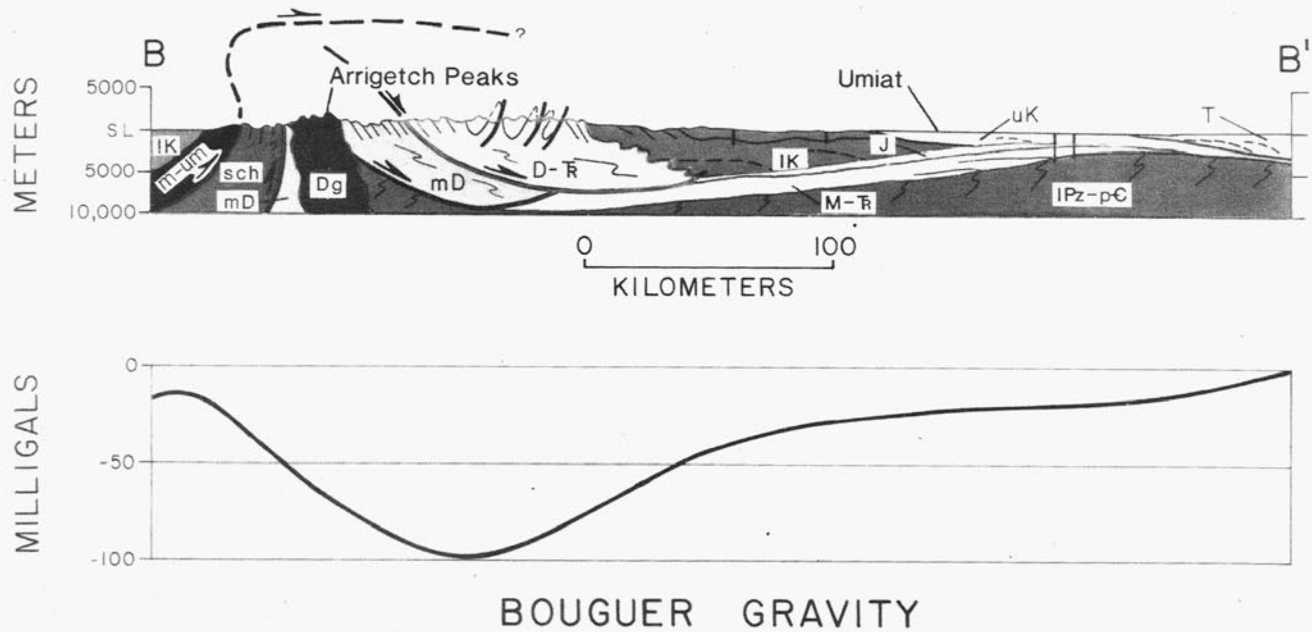


Figure 11. Section B-B′ from Angayucham Mountains to Colville River delta. See Figure 3 for explanation of symbols.

lationships of the frontal ranges.

Section A-A′ Schwatka and Western Endicott Mountains

Section A-A′ (Figure 6) extends from the Angayucham Mountains on the south, across the Shishakshinovik pluton, through Howard Pass to Barrow on the north. The north flank of the Shishakshinovik pluton is a critical locality for documentation of the structural style of the Brooks Range because exposed here is the autochthonous Arctic Slope sequence consisting of Kekiktuk Conglomerate, Kayak Shale, Lisburne Group dolomite and Sadlerochit Group sandstone and shale (Mull and Tailleur, 1977, and Mayfield and Tailleur, 1978). The area of exposure is too small to be mapped at the scale of the generalized geologic map. Figure 7 illustrates this stratigraphic sequence, which unconformably overlies the Shishakshinovik pluton and early Paleozoic metasedimentary rocks. The stratigraphic sequence is identical to that of the Arctic Slope subsurface and northeastern Brooks Range, and contrasts markedly with the stratigraphy of the overlying Kugrak allochthon (mD) and Endicott Mountains allochthon (D-TR).

Figure 8 illustrates the regional north dip at the top of the Kugrak allochthon, and Figures 9 and 10 illustrate the regional north dip of the top of the Endicott Mountains allochthon at the north flank of the central Brooks Range.

Four major allochthons overlying the Arctic Slope autochthonous complex are exposed in the line of section A-A′. Regional mapping (Mayfield and others, 1978; Mayfield and Tailleur, 1978) and palinspastic restoration requires that all four of these allochthons be restored to a position south of the Shishakshinovik pluton. A minimum of 450 km (280 mi) of crustal shortening in the western Endicott Mountains is documented by this section.

Section B-B′ Schwatka and Central Endicott Mountains

Section B-B′ (Fig. 11) extends from the Angayucham Mountains across the Arrigetch Peaks to the Chandler Lake area, Umiat, and the Colville River delta on the north. Figure 12 illustrates the altered mafic igneous complex of the Angayucham Mountains. Figure 13 illustrates isoclinal folding that is typical of the schist belt (sch). The structural style of the south side of the Arrigetch Peaks is anomalous because mica-schist and carbonate rocks dip northward beneath the granitic and metamorphic rocks on the south side of the Arrigetch Peaks (Figure 14, and Nelson and Grybeck, 1980). Local north dip in this area is confined only to the area adjacent to the Arrigetch Peaks pluton and may be overturned as a result of middle and Late Cretaceous asymmetrical uplift of the pluton. This structural asymmetry of the pluton is illustrated in mapping by Nelson and Grybeck (1980).

The Arrigetch Peaks pluton, consisting dominantly of granite gneiss (Fig. 15), forms some of the most precipitous terrain in the Brooks Range. A pervasive foliation is visible in most portions of the pluton. Figure 16, on the north flank of the pluton is typical of the regional north dip on the north flank of the Schwatka Mountains anticlinorium.

Figure 17 illustrates the regional north dip at the central Brooks Range mountain front in the Chandler Lake area. In this area several smaller scale anticlines are superimposed on the regional north dip of the Endicott Mountains allochthon. North of the mountain front, a broad belt of Lower Cretaceous shale and sandstone and isolated blocks of chert, mafic igneous rocks, and other lithologies may represent an olistostrome or intense tectonic dismemberment at the base of an overlying allochthon. Minimum shortening in the line of section B-B′ is 270 km (170 mi).

Section C-C′ Eastern Endicott Mountains

Section C-C′ (Fig. 18) extends across Mt. Doonerak and the eastern Endicott Mountains to the mountain front near Shainin Lake and north to Prudhoe Bay. Regional south dip on the south flank of the range is illustrated in Figure 19.

The Mt. Doonerak area and the Shishakshinovik pluton area (Section A-A′) are the two most important localities for documentation of the structural style of the central Brooks Range. In the Mt. Doonerak area north dipping autochthonous Arctic Slope stratigraphic sequence is well exposed at a number of localities along a 30 km (18 mi) trend that extends from the North Fork of the Koyukuk River to the Dietrich River. Along the

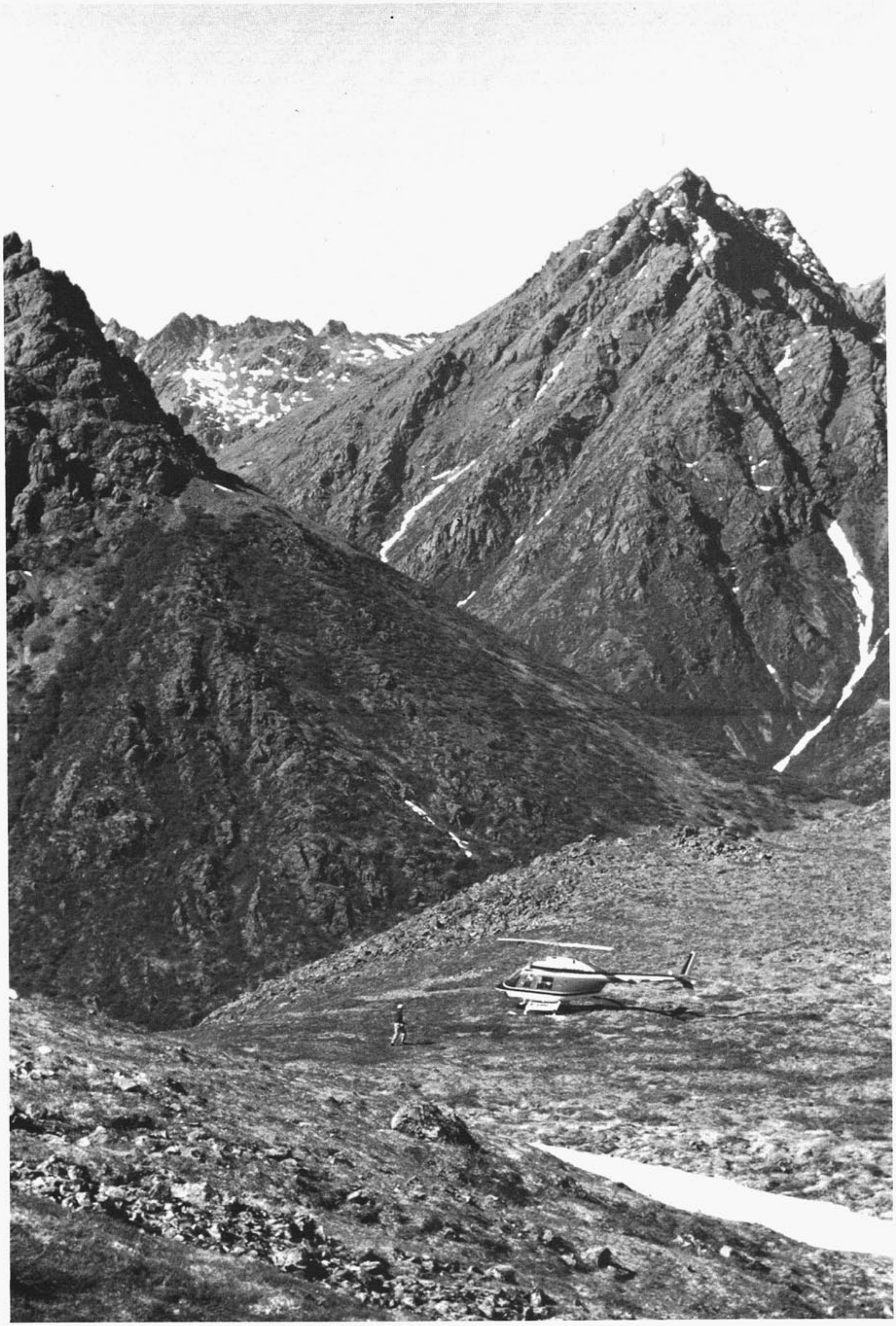


Figure 12. Southwestern view of Angayucham Mountains, near Lake Selby, northwestern Hughes quadrangle. Altered pillow basalts dip steeply southward. Vertical relief is approximately 600 m (2000 ft).

Figure 13. Isoclinal folding of Early Paleozoic marble, upper Mauneluk River, southwest Survey Pass quadrangle. Mountainside is about 460 m (1500 ft high).

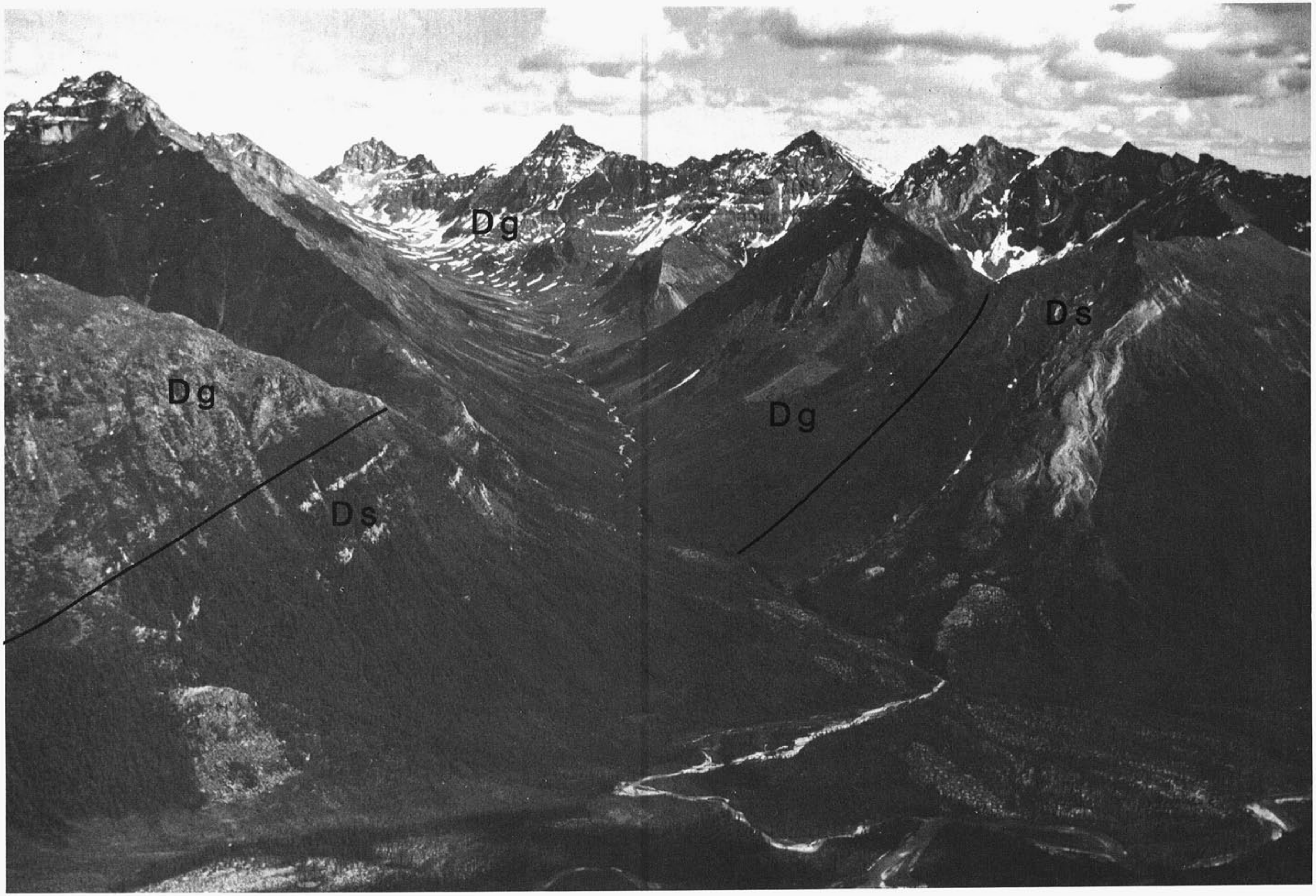


Figure 14. View of south margin of Arrigetch Peaks pluton, upper Kobuk River, Survey Pass quadrangle. Skajit Limestone (Ds) dips northward beneath margin of pluton (Dg). Topographic relief is about 1200 m (4000 ft).

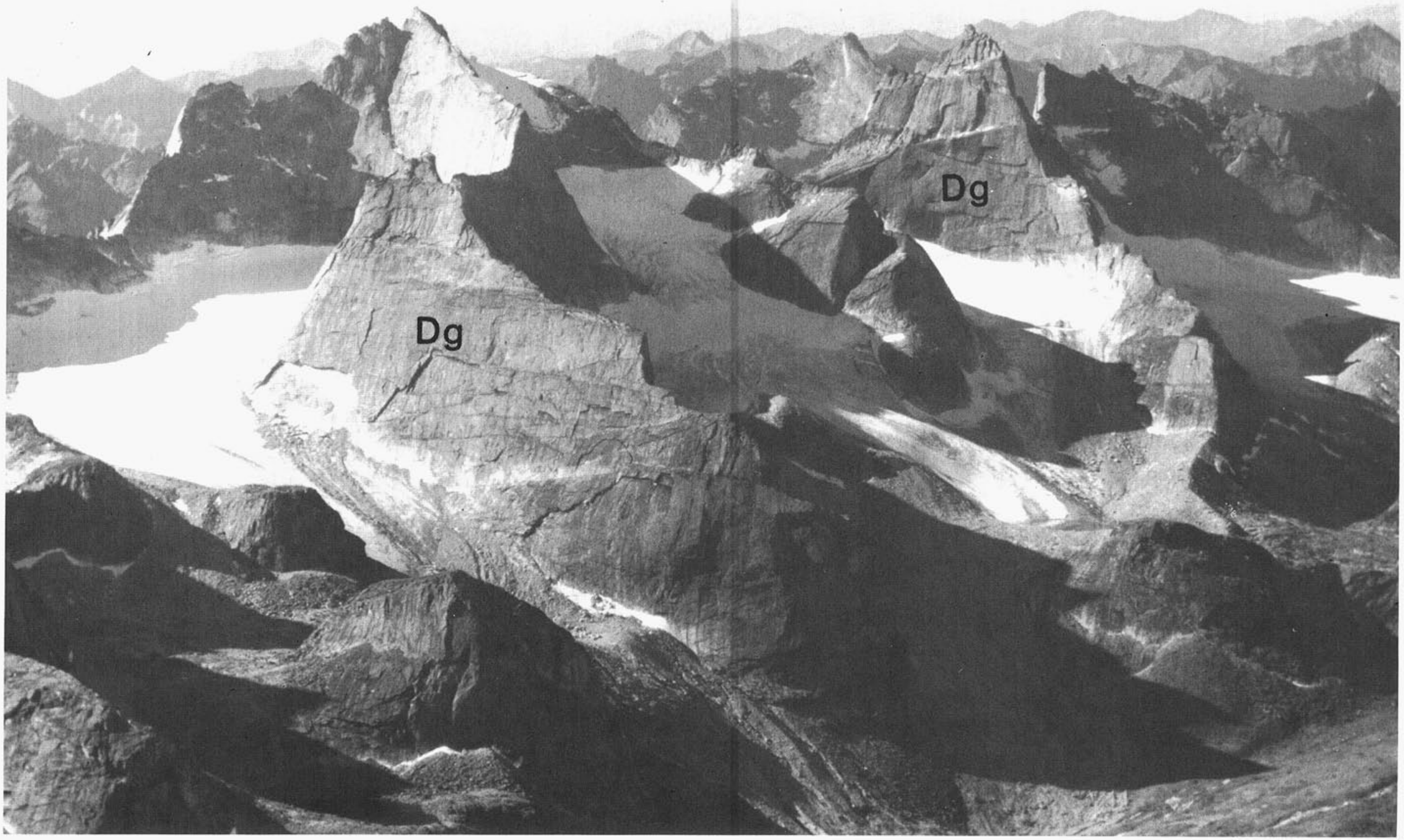


Figure 15. Arrigetch Peaks granite and granitic orthogneiss (Dg) in core of Schwatka Mountains, Survey Pass quadrangle. U-Pb dates and stratigraphic evidence (Fig. 7) indicate that this and other plutons in the Schwatka Mountains are pre-Mississippian in age. K-Ar dates of 90 my to 110 my (Albian to Turonian) suggest that the K-Ar clock was reset during the later part of the Cretaceous orogeny in the Brooks Range.

Figure 16. Westward view of north flank of Schwatka Mountains north of Arrigetch Peaks, Survey Pass quadrangle. Devonian metasedimentary rocks have regional north dip. Topographic relief is about 600 m (2000 ft).

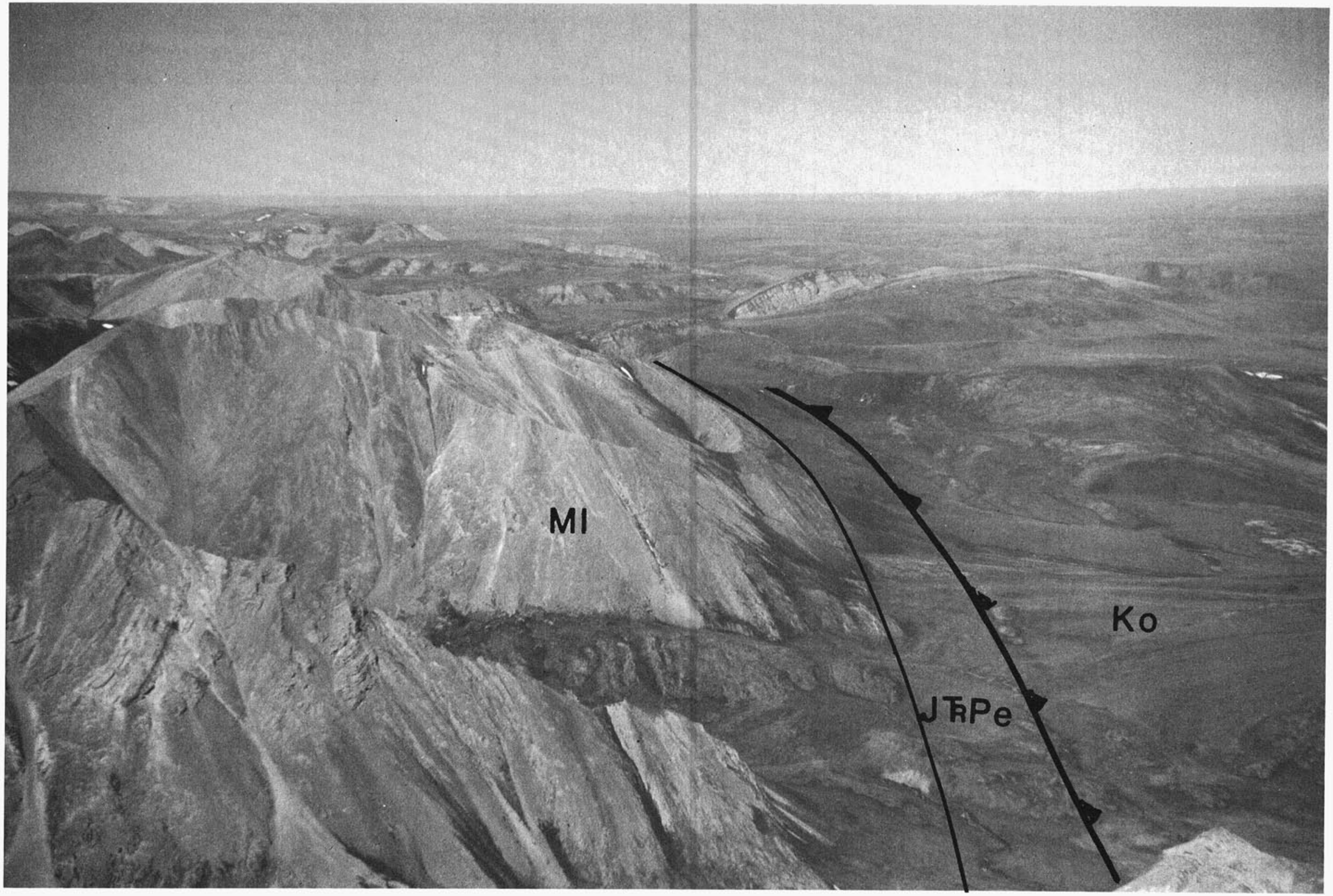


Figure 17. Westward view of Endicott Mountains allochthon at Endicott Mountains front near Confusion Creek, Chandler Lake quadrangle. Lisburne Group limestone (Ml) and discontinuous exposures of siliceous beds of the conformably overlying Permian Siksikpuk Formation and Upper Triassic Otuk Formation, which comprise the Etivluk Group (J Ꞧ Pe), dip 45° to 60° north beneath the Arctic Slope. Slivers of other allochthons and Lower Cretaceous shale of the Okpikruak Formation (Ko) on an overlying allochthon are present in discontinuous exposures to the north. Topographic relief is about 460 m (1500 ft).

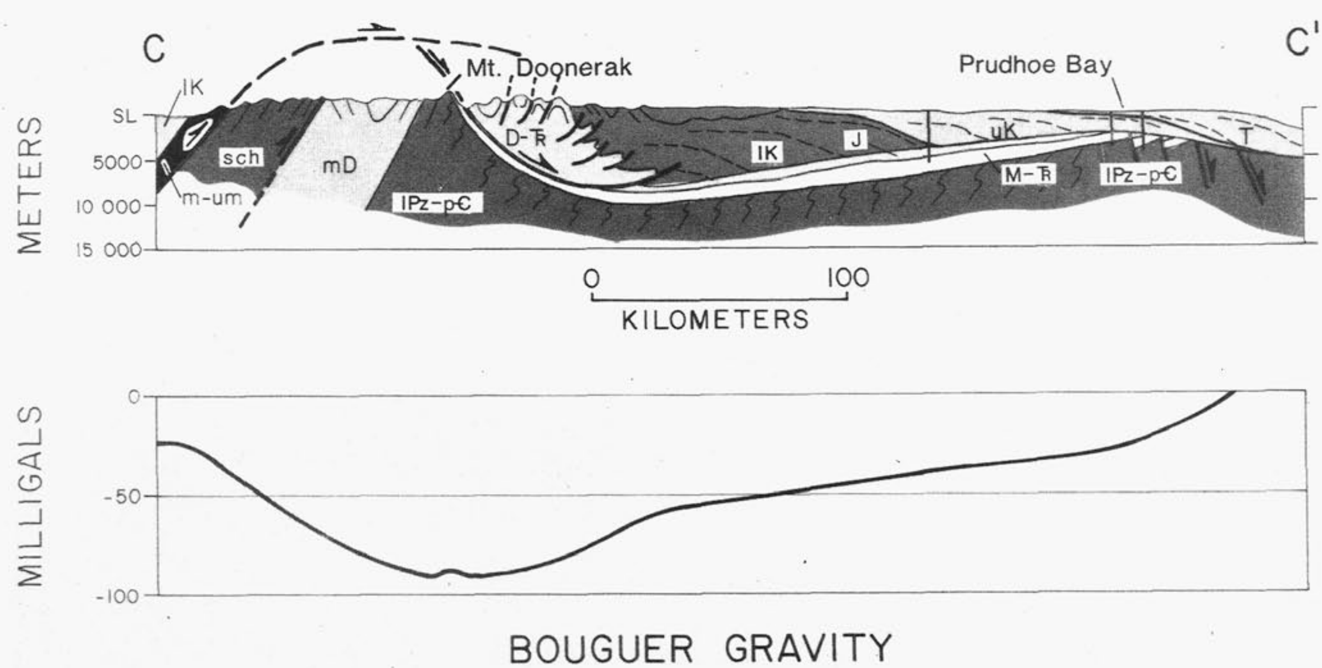


Figure 18. Section C-C′ across eastern Endicott Mountains, Mt. Doonerak to Prudhoe Bay. Small positive anomaly in center of gravity low coincides with outcrop belt of Early Paleozoic volcanic rocks in Mt. Doonerak area. See Figure 3 for explanation of symbols.

trend are excellent exposures of Kekiktuk Conglomerate, Kayak Shale, Lisburne Group, Sadlerochit Group, Shublik Formation, and probable Karen Creek Sandstone. Some of the details of the stratigraphy and structural relationships have been described and alternative interpretation discussed by Dutro and others (1976) and by Armstrong (1976). The similarity of parts of the section to the northeastern Brooks Range was discussed by Dutro and others, who favored a structural interpretation in which the rocks here assigned to the Endicott Mountains allochthon were considered to be autochthonous. Interpretations of the area are controversial, and because of the tectonic significance of the area, previously unpublished data that strengthen the correlation with the northeastern Brooks Range are here presented.

The Amawk Creek valley (Fig. 20) contains excellent exposures of the Lisburne Group, Kayak Shale, and Kekiktuk Conglomerate unconformably overlying Early Paleozoic metamorphic rocks. Sadlerochit Group rocks in the Mt. Doonerak area and the allochthonous relationship of the northern Endicott Mountains were first recognized at this locality on the north side of the Amawk Creek valley. At this locality (71AMu672) and at Bombardment Creek 11 km (7 mi) to the west, the Sadlerochit consists of yellowish brown weathering slightly calcareous burrowed siltstone containing the trace fossil *Zoophycos* (Fig. 21) and scattered brachiopod molds and fragments. *Zoophycos* is an indicator of shallow water and slow rates of deposition, and is abundant in the Echooka Formation of the Sadlerochit Group in the northeastern Brooks Range (Detterman, 1970, p. 0-2.) Detterman and others (1975, p. 10) state that

> "The trace fossil *Zoophycos* is found throughout the Echooka Formation. *Zoophycos* is long ranging but in northern Alaska is known only from the Echooka Formation, and is considered a diagnostic fossil for the stratigraphic unit."

In discussing the fossils from 71AMu672, J.T. Dutro, Jr. (written communication, November 9, 1971) states that:

> "They (the brachiopods) seem to be linoproductids of *Anidanthus-Megousia* lineage, more likely the latter, as a partial "ear" is preserved. In any case, this is a form encountered in Sadlerochit faunas but never in Siksikpuk ones, to my knowledge.
>
> These meager data support the idea that you do, indeed, have Sadlerochit represented here. Of course, the reported presence of *Zoophycos*, together with the nature of the iron-rich calcareous fine-grained sandstone in which the fossils occur, strengthens the assignment."

Overlying the Sadlerochit Group siltstone on the north side of Amawk Creek is about 30 m (100 ft) of unfossiliferous black silty shale that resembles the Kavik Shale of the northeastern Brooks Range and a 30 m (100 ft)-thick thrust sliver of Lisburne Group limestone. Foliated meta-conglomerate and phyllite assigned to the base of the Late Devonian Hunt Fork Shale overlies the Lisburne. The north-dipping Amawk thrust fault here is the basal thrust of the Endicott Mountains allochthon and separates it from the autochthonous complex. Seven miles west of the Amawk Creek exposures, the Sadlerochit Group and overlying Shublik Formation are well exposed in a narrow canyon at the mouth of Bombardment Creek on the north side of Mt. Doonerak. The Shublik consists of black earthy shale and limestone containing scattered phosphate nodules. At the top of the Shublik Formation is an unfossiliferous 3-m (10 ft)-thick dense dark gray to black siltstone (Fig. 22). Although no fossils are present, based on lithology and stratigraphic position, this siltstone is correlated with the Karen Creek Sandstone of the northeastern Brooks Range.

The Amawk thrust can be traced along the entire north side of the Doonerak uplift. Along its entire mapped extent the Amawk thrust fault and overlying Hunt Fork and Kanayut have regional north dip. To the north the Endicott Mountains allochthon is folded into a series of anticlinoria and synclinoria; Figure 23 illustrates the Lisburne Group, Kayak Shale, and Kanayut

Figure 19. Eastward view of southern Endicott Mountains, Wild River area, southern Wiseman quadrangle. Early Paleozoic marble and phyllite dips regionally southward beneath mica schist. Topographic relief is about 600 m (2000 ft).

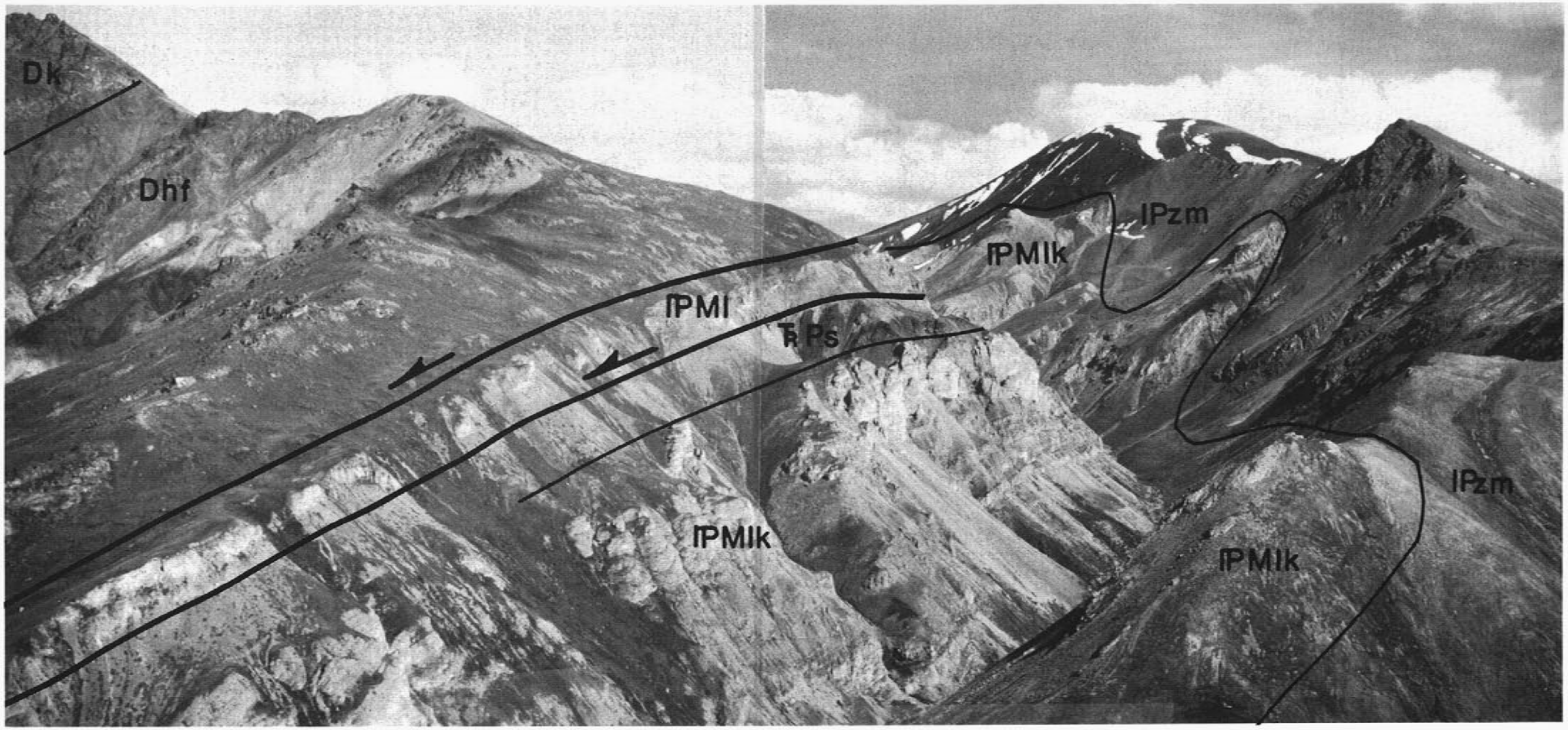


Figure 20. Eastward view along Amawk Creek valley, Mt. Doonerak area, northeastern Wiseman quadrangle. Autochthonous Sadlerochit Group sandstone and shale (TR Ps), Lisburne Group limestone, Kayak shale, and Kekiktuk Conglomerate (IPMlk) dip northward and unconformably overlie steeply south dipping Early Paleozoic metavolcanic rocks and phyllite (lPz m). Sadlerochit Group is overlain by a thrust sliver of Lisburne Group (IP Ml). Shale, schistose phyllite, and schistose conglomerate at the base of the Upper Devonian Hunt Fork Shale (Dhf) overlie the Amawk thrust, the sole fault of the Endicott Mountains allochthon. Kanayut Conglomerate (Dk) forms the higher mountains to the north. The presence of Sadlerochit Group along the Doonerak structural trend was first recognized at this locality.

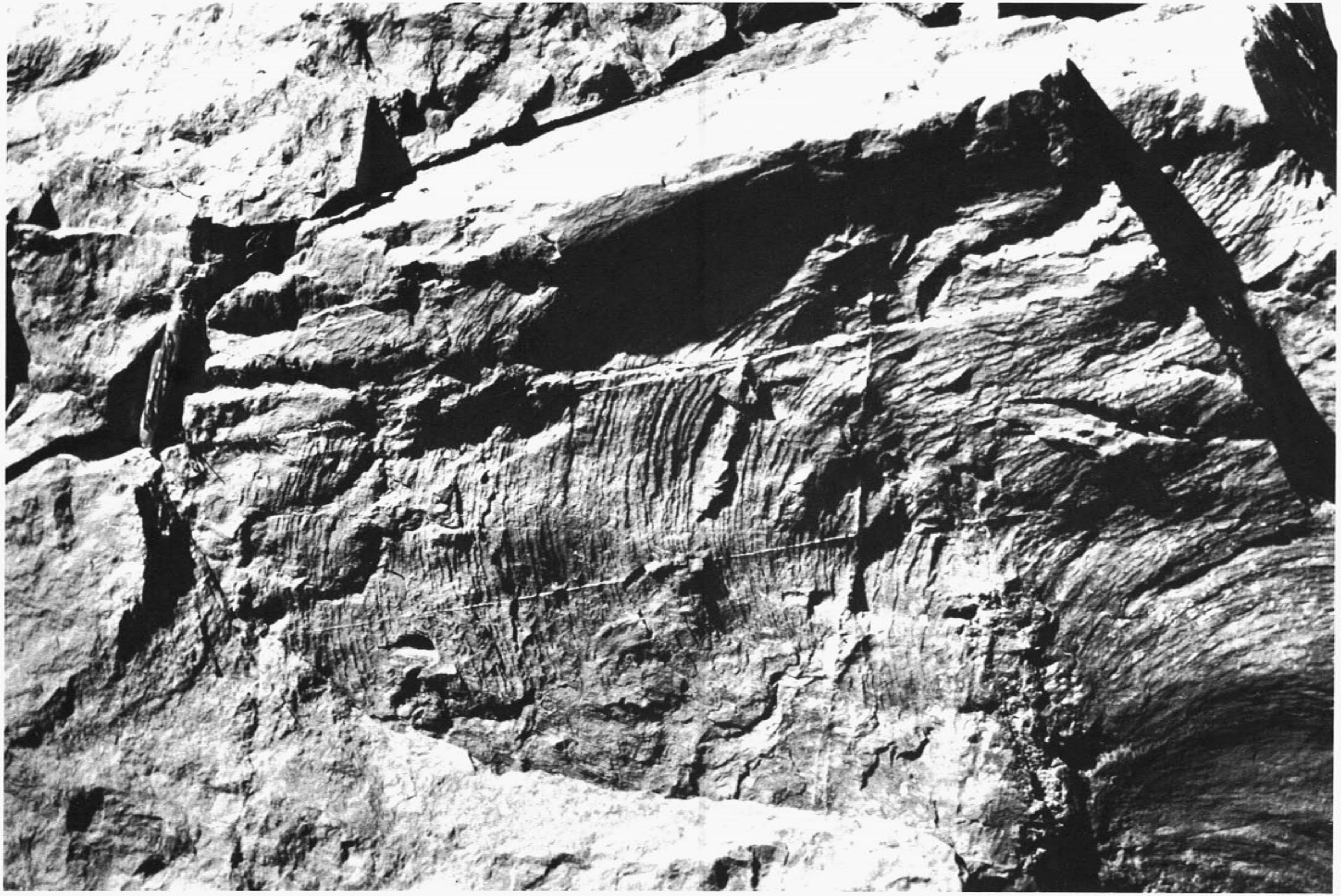


Figure 21. *Zoophycos*, a trace fossil from the lower part of Sadlerochit Group, Amawk Creek, Mt. Doonerak area, northeastern Wiseman quadrangle. Similar trace fossils are found in the Sadlerochit at Bombardment Creek, 11 km (7 mi) west of the Amawk Creek locality. Note pocket knife for scale at left.

Figure 22. North dipping Karen Creek Sandstone at Bombardment Creek, north side of Mt. Doonerak, northeastern Wiseman quadrangle. Shublik Formation and Sadlerochit Group conformably underlie this unit.

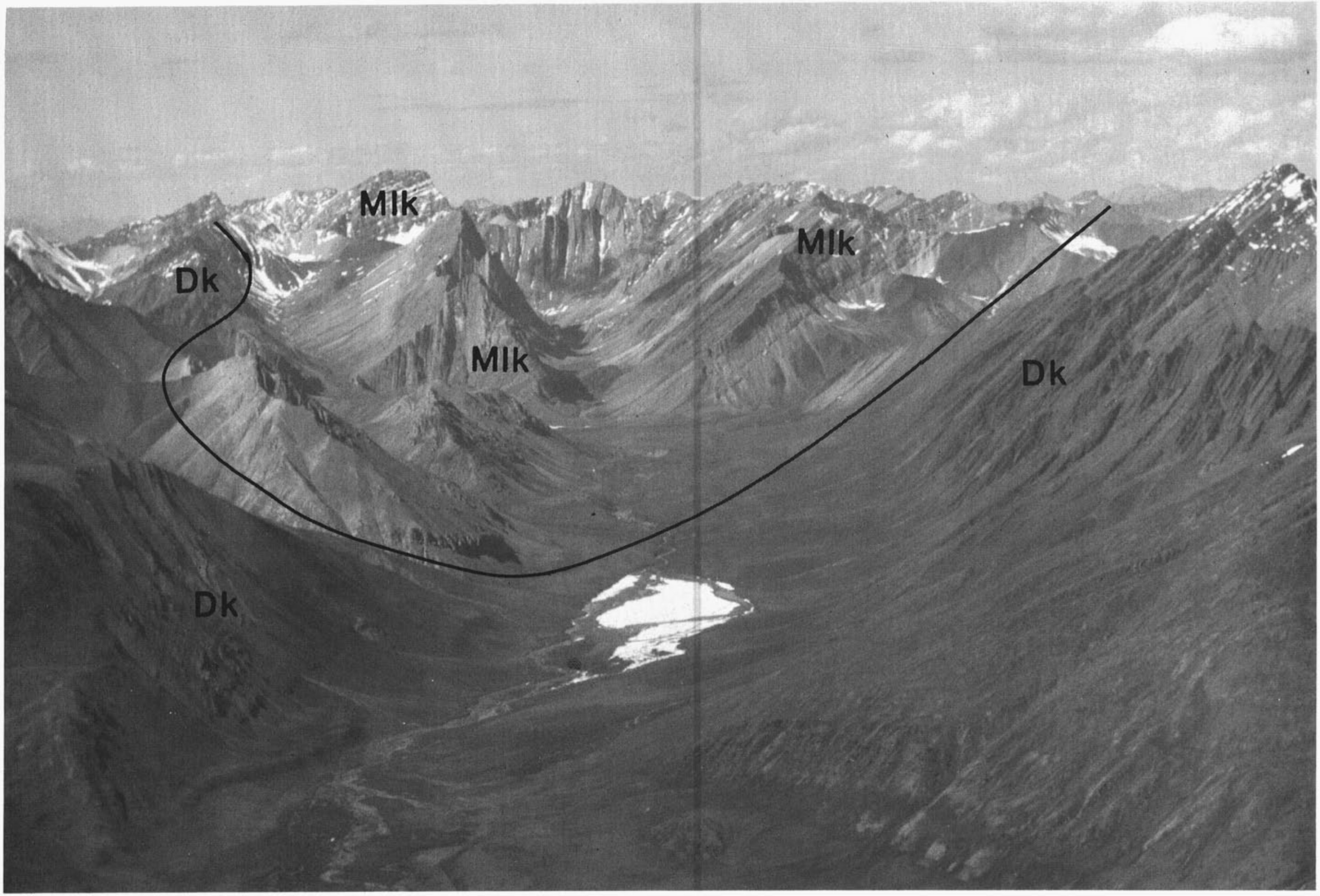


Figure 23. Westward view of Endicott Mountains, upper Itkillik River area, eastern Chandler Lake quadrangle. Mississippian Lisburne Group limestone and Kayak Shale (Mlk) conformably overlie Upper Devonian Kanayut Conglomerate (Dk) in a regional syncline in the Endicott Mountains allochthon. Topographic relief is 600-900 m (2000-3000 ft).

Figure 24. Northeastward view of Endicott Mountains front near Shainin Lake, Chandler Lake quadrangle. Lisburne Group carbonate rocks (Ml), Kayak Shale (Mk), and Kanayut Conglomerate (Dk) on Endicott Mountains allochthon dip 30° N on the north flank of a regional anticline that forms the mountain front. Topographic relief is 300-600 m (1000-2000 ft).

Figure 25. Eastward view of Endicott Mountains front near Atigun River, western Philip Smith Mountains quadrangle. Mississippian Lisburne Group Limestone on Endicott Mountains allochthon dips 60° to 70° N. Topographic relief is about 300 m (1000 ft).

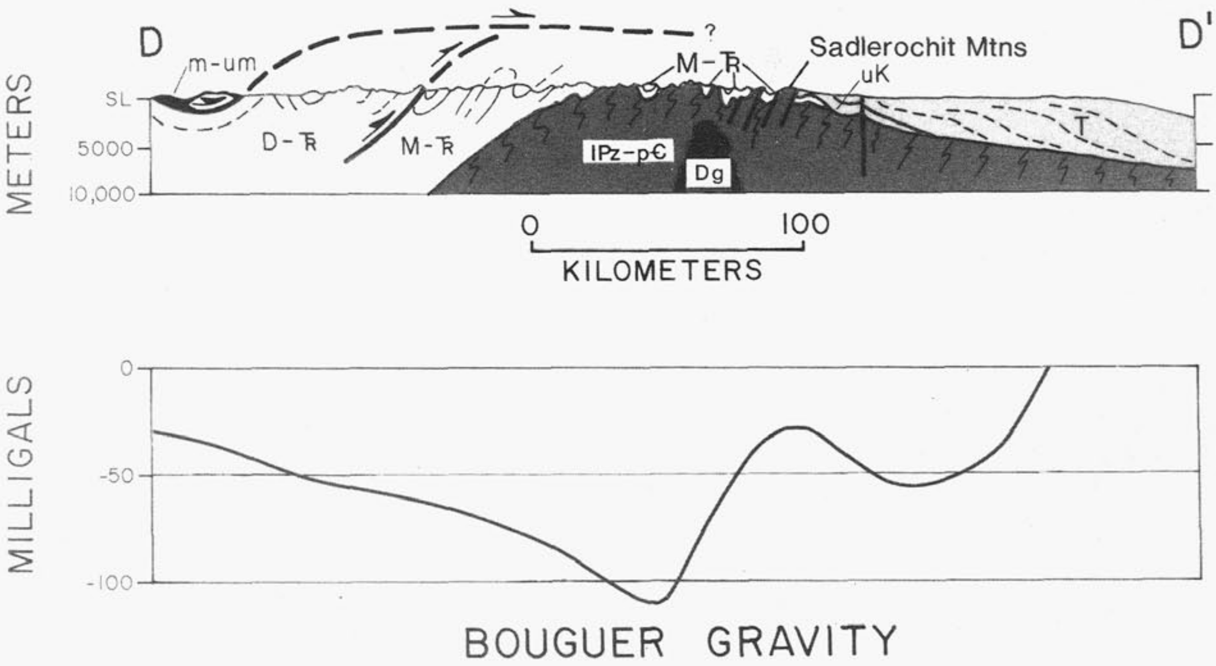


Figure 26. Section D-D′ across eastern Brooks Range. See Figure 3 for explanation of symbols.

Conglomerate in one of these synclinoria. Complex folds and numerous thrust faults involving Lisburne Group carbonate rocks, Kayak Shale, and Kanayut Conglomerate are superimposed on the regional structural style.

Regional north dip characterizes the front of the eastern Endicott Mountains (Figs. 24 and 25). In some places the Lisburne at the mountain front is overturned or otherwise complicated by intra-allochthon thrust faults and folds. Discontinuous exposures of the Permian to Upper Triassic Etivluk Group overlie the Lisburne along the eastern Endicott Mountains front. In this area the Siksikpuk Formation is dominantly black shale with abundant barite nodules and lenses; (Mull, unpublished field notes, 1982, and Sellers, 1981). The overlying Upper Triassic section consists dominantly of black earthy shale and limestone with scattered silicified limestone beds. (Mull, unpublished field notes, 1982). The section seems to be transitional between the dominantly siliceous sections of the De Long and western Endicott Mountains and the non-siliceous Permian and Triassic section of the autochthonous northeastern Brooks Range. However, although the Permian and Triassic section of the eastern Endicott Mountain front is less siliceous than to the west, it contrasts with the Sadlerochit and Shublik of the Mt. Doonerak area, which contains no silicified beds or barite. The facies and structural relationships indicate minimum crustal shortening of 56 km (35 mi) in the line of section C-C′.

The northern end of Section C-C′ crosses the Prudhoe Bay oil field and diagrammatically illustrates the normal faults associated with the extensional northern margin of the Arctic Alaska plate. In this area, the Cretaceous and Tertiary molassoid wedge derived from the Brooks Range progrades over and truncates the rifted plate margin. Cretaceous shale with high organic content is considered by many geologists to have been the source of at least most of the hydrocarbons in the Carboniferous, Triassic, and basal Cretaceous reservoirs of the Prudhoe Bay oilfield (Morgridge and Smith, 1972; Jones and Spears, 1976).

Section D-D′ Brooks Range

Section D-D′ (Fig. 26) crosses the eastern Brooks Range from the area of the Christian River on the south across the Romanzof and Sadlerochit Mountains on the north. In the northern part of the eastern Brooks Range, a vertical style of basement-involved uplift characterizes the area, which contains a number of broad anticlinoria and synclinoria developed in Mississippian and younger autochthonous rocks (Figs. 27 and 28). Pre-Mississippian basement is exposed in all of the major anticlines. High-angle reverse faults with regional south dip are present along some of the anticlinoria, but low-angle thrust faults are not present.

In the southern part of the area, the mafic-ultramafic allochthon and Endicott Mountains allochthon are present but do not now extend north to the mountain front. However, clasts of tasmanite, a distinctive type of rich oil shale composed entirely of the spore *Tasmanites*, in early Tertiary conglomerate north of the Sadlerochit Mountains suggest that the allochthons may have had a greater northward extent as late as the early Tertiary. Elsewhere in the Brooks Range, bedrock exposures of tasmanite seem to be closely associated with rocks of the Ipnavik River allochthon — one of the structurally highest allochthons.

OTHER SIGNIFICANT STRUCTURAL FEATURES

Structural features of regional significance in the Brooks Range and out of the line of the cross sections are illustrated in Figures 29 through 35.

Figure 29 shows the structural relationships of the mafic-ultramafic allochthons (Copter Peak and Misheguk Mountains allochthons) in the De Long Mountains. Lisburne Group limestone is overlain by a thrust sheet of altered fine-grained mafic rock that in turn is overlain by a sheet of dunite and gabbro. The dunite is apparently gradational upward into gabbro, but its basal contact is clearly a thrust fault. The Misheguk Moun-

Figure 27. **Eastward view of basal Mississippian angular unconformity in northern Romanzof Mountains, Mt. Michelson quadrangle. Lower Paleozoic metasedimentary basement rocks (lPzm) dip steeply southward; Kekiktuk Conglomerate and Kayak Shale (Mkk), Lisburne Group limestone (IPMl), and Sadlerochit Group sandstone (TR Ps) dip about 60° northward. Topographic relief is about 900 m (3000 ft).**

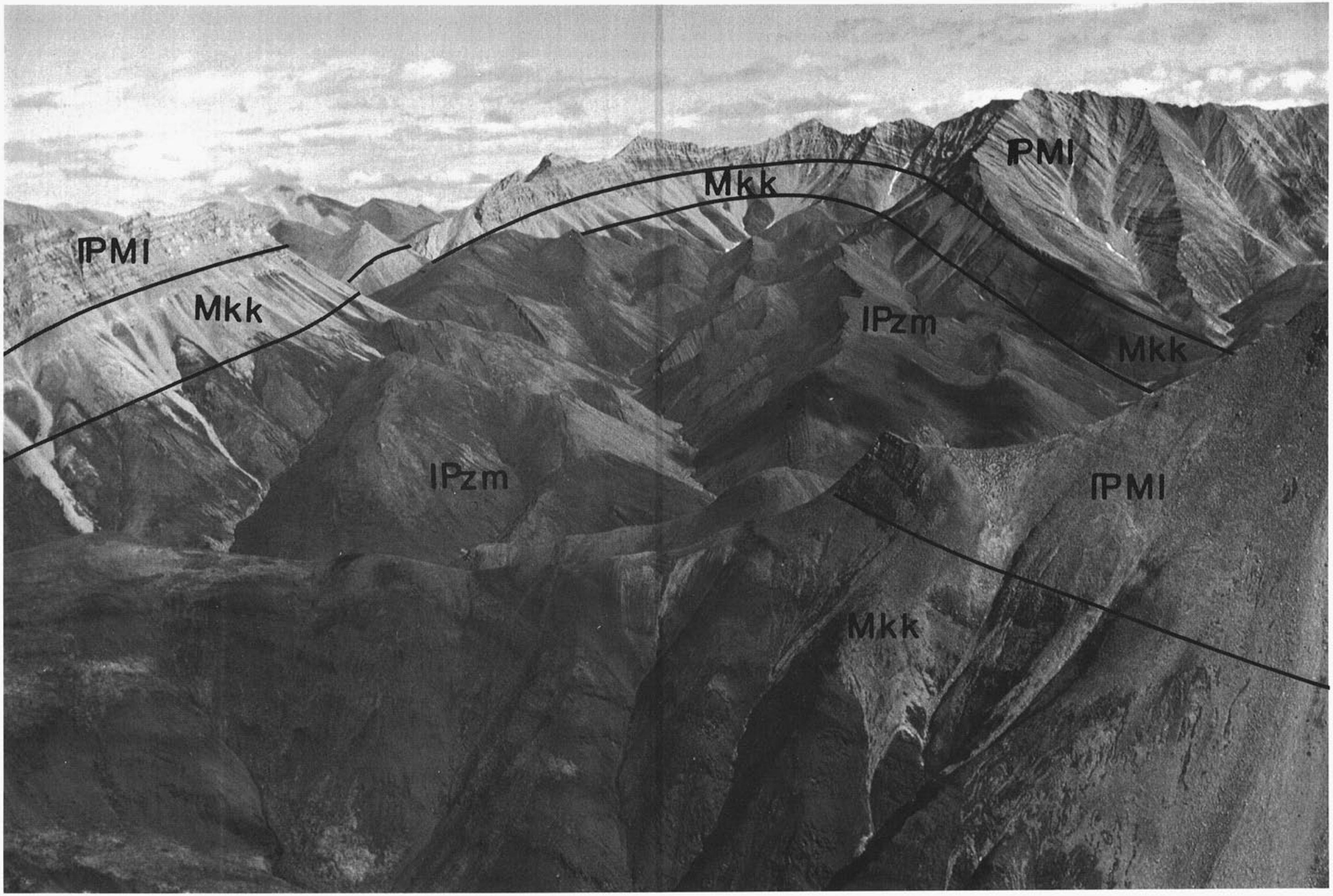


Figure 28. Eastward view of anticlinorium on north flank of Romanzof Mountains, Mt. Michelson quadrangle. Lisburne Group limestone (IPMl), Kayak Shale and Kekiktuk Conglomerate (Mkk) unconformably overlie early Paleozoic metasedimentary basement rocks (IPz m). Topographic relief is about 600 m (2000 ft).

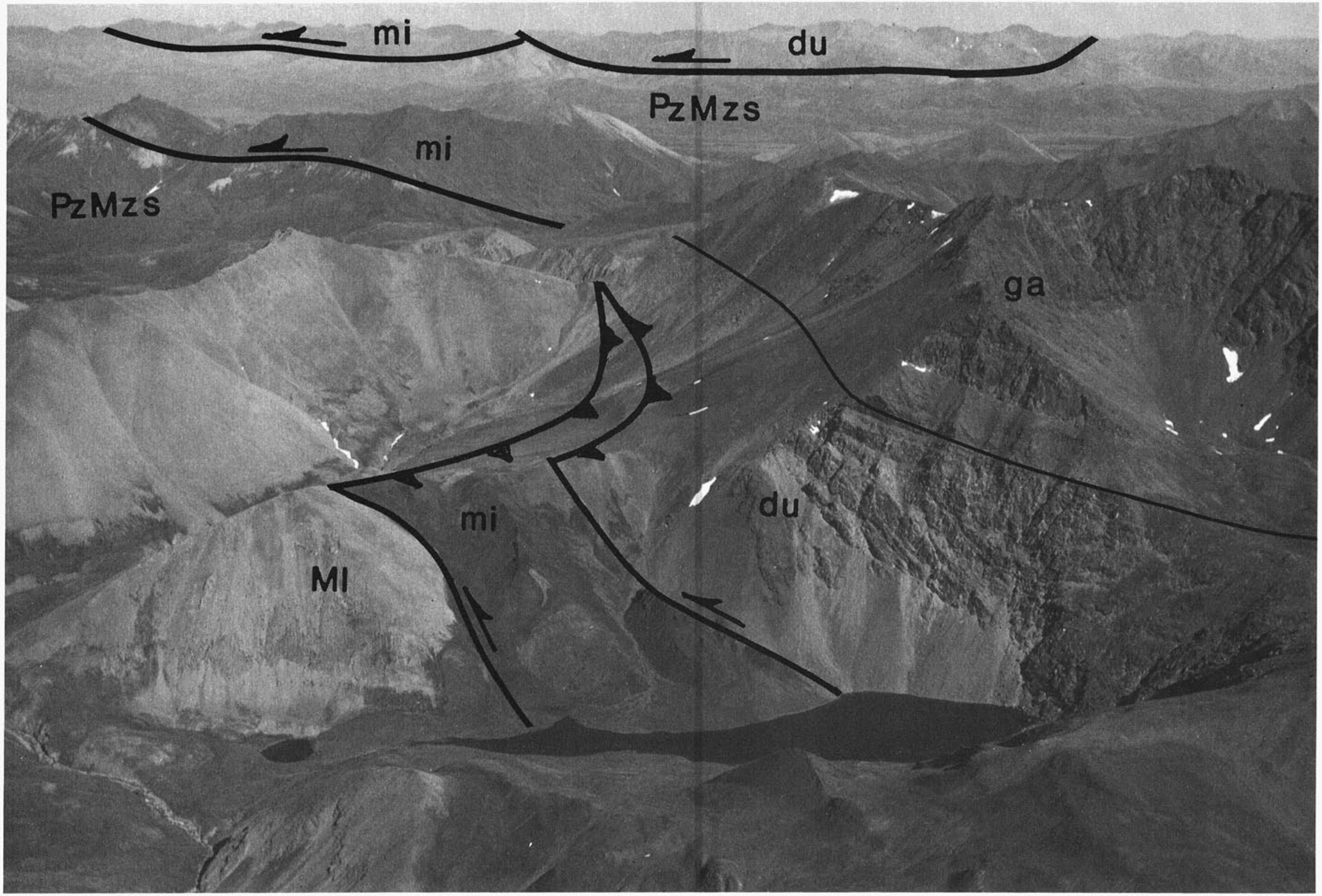


Figure 29. Eastward view of north edge of klippe of dismembered ophiolite in Avan River and Kugururok River area of the De Long Mountains, western Misheguk Mountain quadrangle. Lisburne Group limestone (Ml) is overlain by altered basalts of the Copter Peak allochthon (mi), and dunite (du) and olivine gabbro (ga) of the Misheguk Mountain allochthon. In middle distance, Copter Peak allochthon overlies Paleozoic and Mesozoic sedimentary rocks (Pz Mzs). Misheguk Mountain across Kugururok River valley in far distance, is formed by Misheguk Mountain allochthon (du) in thrust contact overlying Paleozoic and Mesozoic sedimentary rocks (Pz Mzs) in the river valley. Topographic relief is about 600 m (2000 ft).

Figure 30. Westward view of Endicott Mountain front at Killik River, central Killik River quadrangle. Mountain front is formed by overturned thrust sheets of Kayak Shale (Mk) and Lisburne Group limestone (Mlc and Ml) and stratigraphically overlying Etivluk Group (J TR Pe). Kanayut Conglomerate (Dk) forms crest of mountain to left. Topographic relief at mountain front is 600 m (2000 ft).

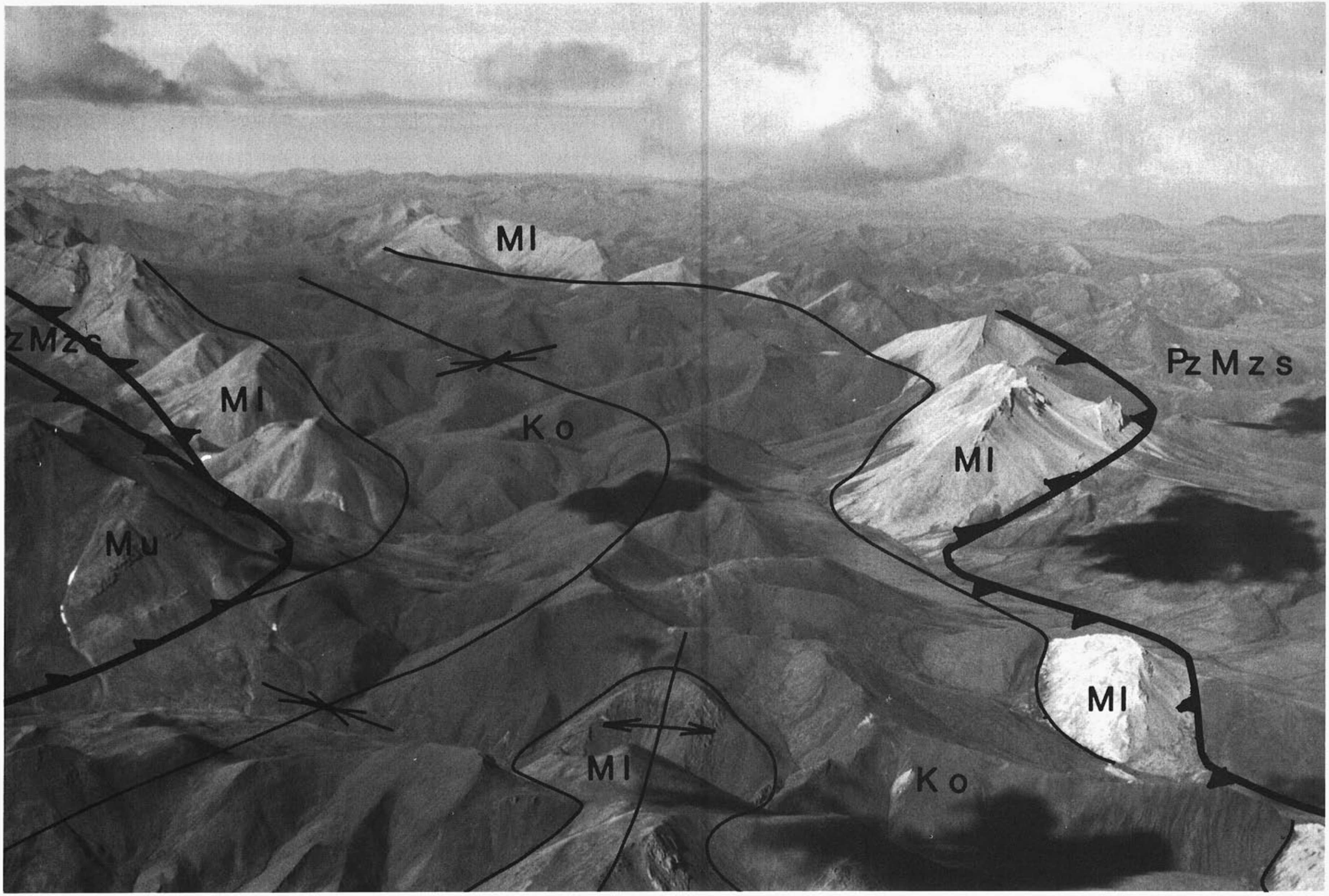


Figure 31. Westward view of central De Long Mountains, western Misheguk Mountain quadrangle. Mississippian Lisburne Group limestone (Ml) and Lower Cretaceous Okpikruak Formation (Ko) in regional syncline on Kelly River allochthon overlies Endicott Mountains allochthon (Pz Mzs) in lowland areas. On left, thrust plate of lower Mississippian Utukok Formation (Mu) of the lower part of Kelly River allochthon overrides south flank of syncline. Topographic relief is 300-450 m (1000-1500 ft).

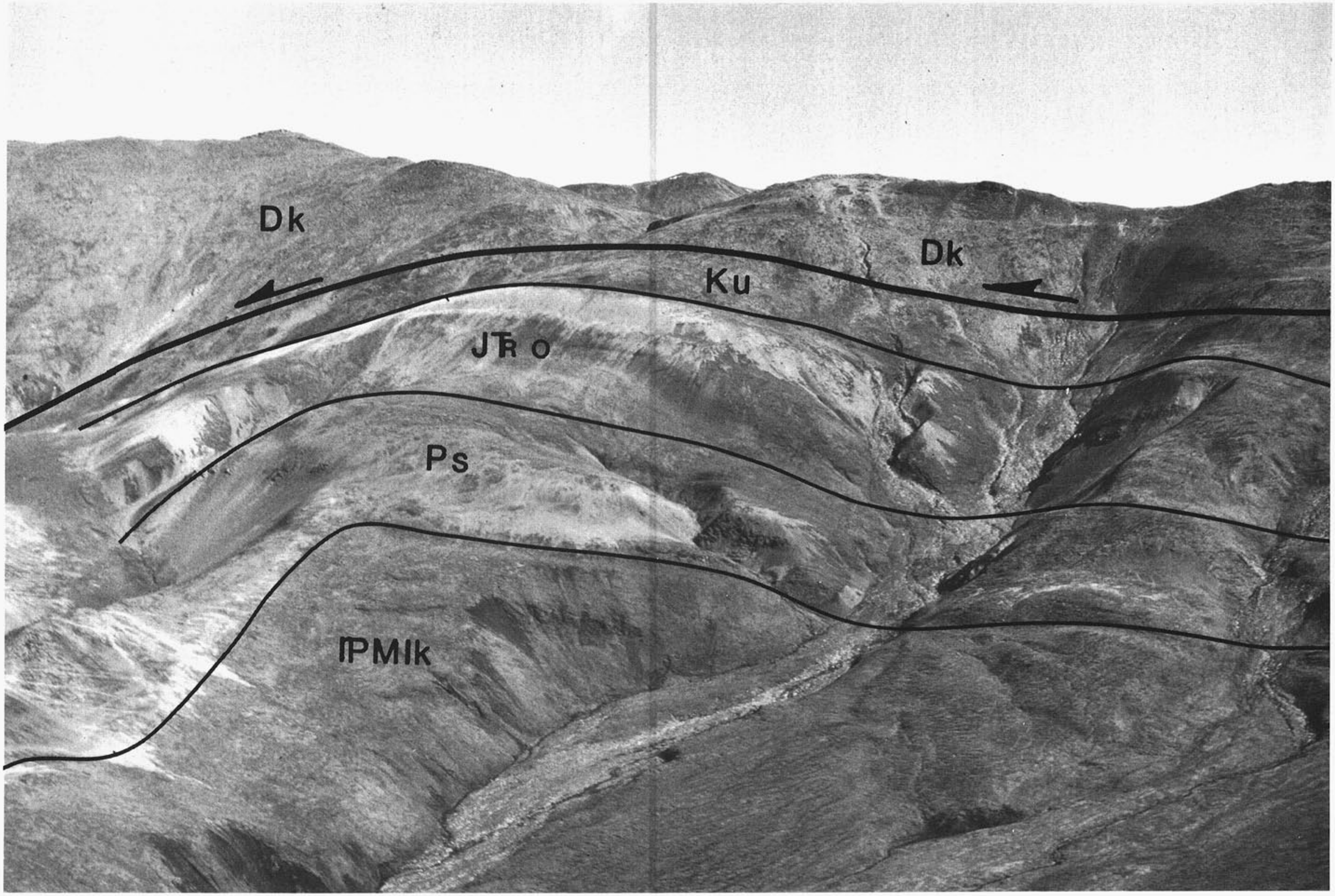


Figure 32. Eastward view of Safari Creek fenster on headwaters tributary of Kuna River upstream from Figure 10, Howard Pass quadrangle. Intra-allochthon thrust faulting within the Endicott Mountains allochthon telescopes Kanayut Conglomerate (Dk) over Cretaceous shale and limestone (Ku), Otuk Formation (JTR o), Siksikpuk Formation (Ps), and Kuna Formation of the Lisburne Group (ℙMlk). Topographic relief is about 300 m (1000 ft).

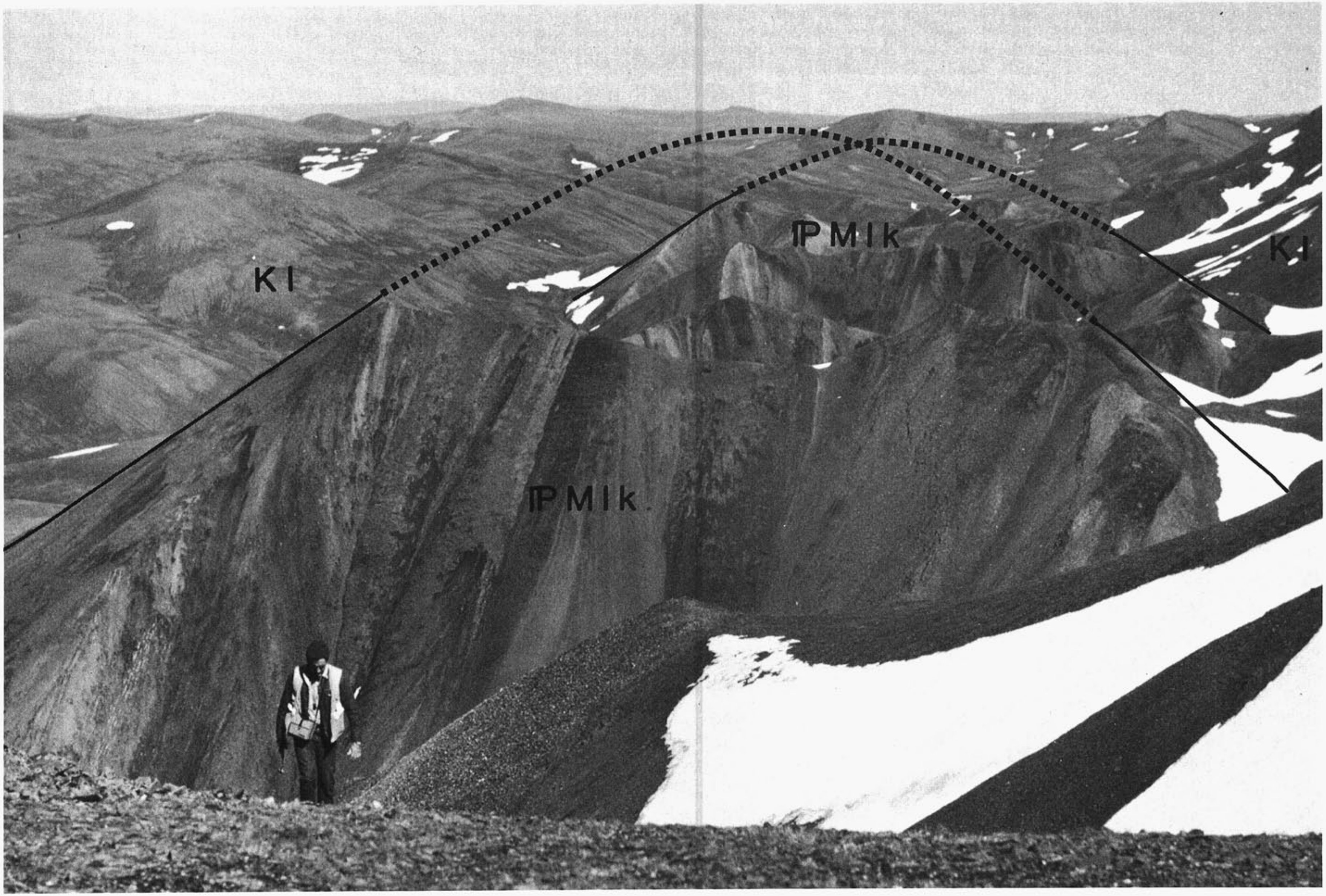


Figure 33. View northeastward along anticline exposing Kuna Formation of Lisburne group on Endicott Mountains allochthon, northwestern De Long Mountains, De Long Mountains quadrangle. Core of anticline exposes Kuna Formation (IP-Mlk) overlain by poorly exposed Permian and Triassic Etivluk Group and Lower Cretaceous graywacke (Kl). This anticlinal trend contains the northernmost exposures of the Endicott Mountains allochthon in the De Long Mountains. Topographic relief is about 230 m (750 ft).

tain complex on the distant skyline in Figure 29 is the largest ophiolitic complex in the western Brooks Range.

Figures 30 and 31 illustrate evidence for multiple stages of deformation of the Brooks Range allochthons. In Figure 30 two discrete sheets of Lisburne Group carbonate rocks on the Endicott Mountains allochthon are telescoped by thrust faulting; stratigraphic top on both sheets is to the right (north). Along strike to the west (right skyline) both thrust plates are nearly vertical, with stratigraphic tops also to the right (north). On the left skyline, Kanayut Conglomerate and Hunt Fork Shale dip to the south and are bounded by a thrust at the base of the section. On the Endicott Mountain allochthon, regionally the Lisburne Group and Kayak Shale stratigraphically overlie Kanayut Conglomerate (see Figs. 9, 23 and 24), but locally a thrust fault within the Endicott Mountains allochthon separates these rock units. The extreme overturning of the two thrust sheets of Lisburne Group rocks is most easily interpreted as the result of drag by movement of the thrust plate of Kanayut and Hunt Fork subsequent to the thrust superposition of the two sheets of Lisburne.

Figure 31 illustrates a regional syncline developed in rocks of the Kelly River allochthon. Early Cretaceous flysch of the Okpikruak Formation overlies thin, poorly exposed Etivluk Group, and Lisburne Group limestone which forms the flanks of the syncline. At the base of the Lisburne is a thrust fault overlying rocks of the Endicott Mountains allochthon. On the left, the Lisburne of the south flank of the syncline is overridden by a south-dipping thrust plate composed of Lower Mississippian Utokok Formation of the Lisburne Group — a lower part of the Kelly River allochthon. The regional relationships are most easily explained by two stages of deformation — an early stage of thrust telescoping of the Kelly River and Endicott Mountains allochthons followed by a later stage of regional folding and rethrusting.

Figure 32 illustrates intra-allochthon deformation and thrust telescoping within the Endicott Mountains allochthon. Regionally the Kuna Formation of the Lisburne Group and Kayak Shale overlies Kanayut Conglomerate (Figs. 9, 10), but is here also overlain by a thrust sheet of Kanayut. The magnitude of intra-allochthon deformation in the Brooks Range is difficult to document but greatly increases the amount of crustal shortening calculated from the amount of tectonic overlap of the major allochthons.

Figure 33 illustrates the style of deformation of the Endicott Mountains allochthon in the northwestern De Long Mountains quadrangle. Relatively incompetent beds of the Kuna Formation and the Etivluk Group are exposed in a series of tight anticlines that lie to the north of and structurally beneath the Kelly River allochthon (Fig. 37).

Deformation of the Albian molassoid wedge north of the Brooks Range is illustrated in Figures 34 and 35. A mosaic Landsat image of the foothills of the De Long Mountains shows the long linear anticlines and synclines that characterizes the décollement of the northern foothills. Resistant sandstone beds of the Albian Nanushuk Group form most of the synclines, which stand as mesa-like erosional remnants that rise above anticlinal valleys eroded in tightly crumpled nonresistant shale of the Albian Torok Formation. The structural style and seismic data indicate that this style of deformation does not persist in the underlying Triassic and older sediments. Figure 35 is a closer view of one of the synclinal remnants of the Nanushuk Group.

DIRECTION AND MAGNITUDE OF TECTONIC TRANSPORT

The direction of relative thrust transport of some of the allochthons of the Brooks Range has been the subject of controversy. The interpretation favored here is of relative northward transport of all the allochthons over the autochthonous Arctic Slope complex (or the inverse relationship — relative southward under-thrusting of the Arctic Slope beneath the central and western Brooks Range as proposed by Tailleur in 1973). However, in the Mt. Doonerak area, Dutro and others (1976) favored an interpretation in which the relative motion of the rocks here considered to be part of the Endicott Mountains allochthon was from north to south over the autochthonous Doonerak sequence. In the western Brooks Range, Churkin and Nokleberg (1979) favored an interpretation in which one of the allochthons had relative south to north transport. Their interpretation was questioned by Crane (1980), Mayfield (1980), and Mull (1980) and is not supported by the regional structural style and facies distribution documented here.

Grybeck and Nelson (1981) carried out a structural analysis of the Survey Pass quadrangle; the southern two-thirds of this quadrangle lies within the metamorphic and igneous core of the Brooks Range. Their analysis documented pervasive recumbent isoclinal folding that they suggest is probably related to Devonian orogeny. They also note regional doming over the Mt. Igikpak and Arrigetch Peaks plutons. Their data in the area here considered to be within the southern part of the belt of major allochthons indicated numerous large open to chevron folds with flat, nearly east-west trending axes and fanned axial planes that strike parallel the trend of the folds. No indication of direction of vergence was observed, however.

Detailed structural fabric studies have not been carried out in the frontal portions of the Brooks Range; however, scattered observations support the interpretation of relative northward transport of the allochthons or the inverse-southward underthrusting. South-dipping axial planes of major folds in the western Brooks Range suggest that the structurally higher allochthons were thrust relatively northward (Mayfield, 1980). In addition, northward tectonic transport of the Endicott Mountains allochthon in the Mt. Doonerak area is suggested by prominent slaty cleavage observed at several localities in rocks of both the Shublik Formation and Sadlerochit Group (Fig. 36) of the autochthonous complex. Additional evidence for northward transport of allochthons in the De Long Mountains of the western Brooks Range is also illustrated in Figure 37. In this area, rocks of the Kelly River allochthon are folded into a series of anticlines and synclines; the axis of one of anticlines lies to the right (south) of the view of Figure 37. In one area, vertical beds of the Lisburne Group are clearly cut by prominent north-dipping shear zones (or mega-cleavage) with minor slip offset. The dip on the shear zones is not compatible with axial plane cleavage associated with the anticline to the south. The orientation and slip on the shear surfaces suggests northward transport of the overlying beds relative to the Lisburne Group prior to uplift and folding of the allochthons.

Interpretation of the evidence discussed above is not unique; other structural scenarios can be inferred. However, the interpretation is compatible with the regional stratigraphic and structural relationships discussed in this paper.

An estimate of the magnitude of crustal shortening in the Brooks Range can be obtained by palinspastic restoration of the major allochthons. The sum of the documented tectonic overlap of each major allochthon over the underlying allochthon, measured parallel to the direction of assumed shortening, yields a minimum estimate of the amount of shortening in that portion of the orogenic belt. This estimate does not take into account the amount of intra-allochthon deformation. In addition, in the palinspastic restoration, the estimate does not take into

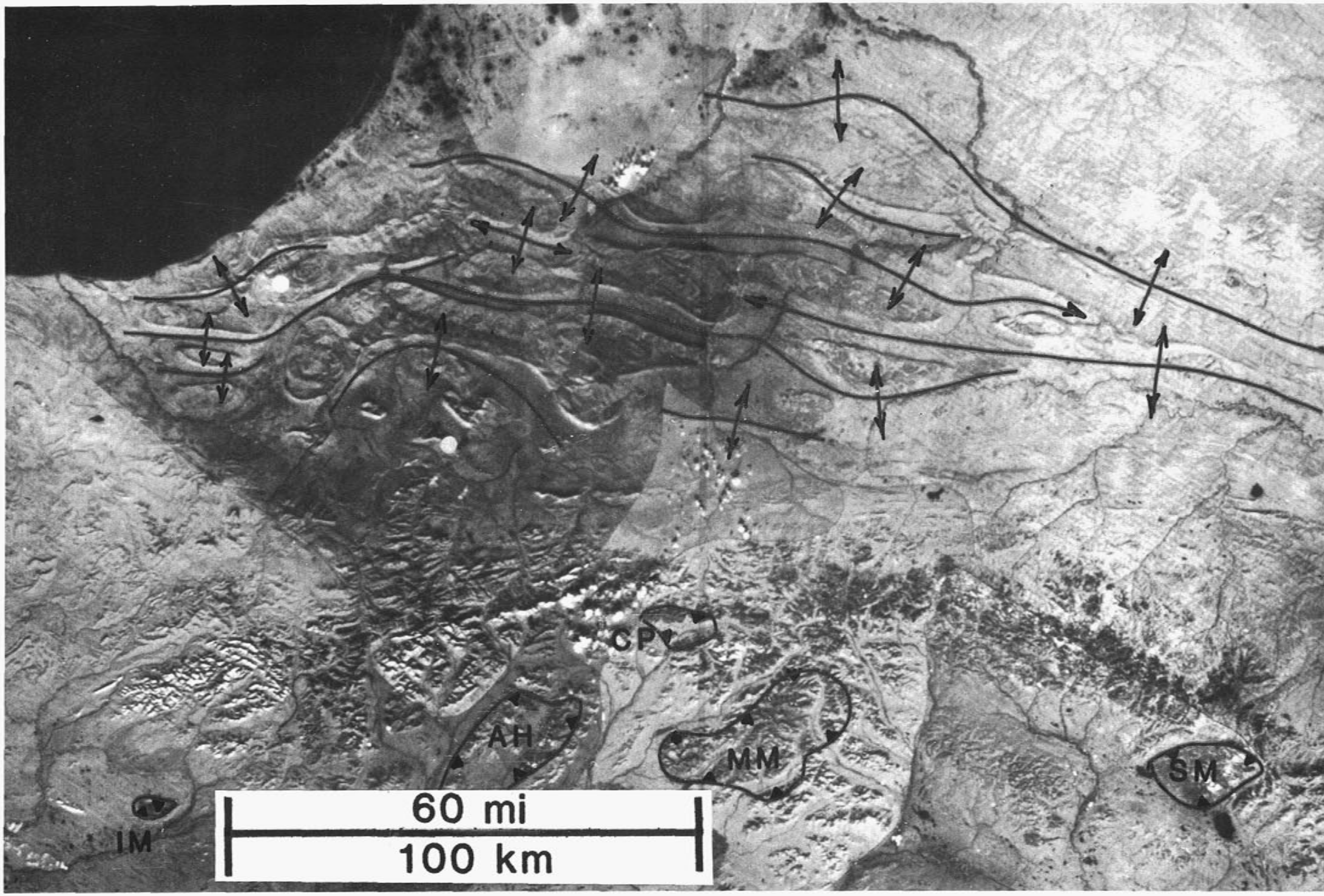


Figure 34. Mosaic Landsat image of De Long Mountains and foothills, western Arctic Slope. Long linear anticlines and synclines in foothills are developed in clastic rocks of the Lower Cretaceous Nanushuk Group. Light-colored areas in mountains are dominantly Lisburne Group limestone of the Kelly River allochthon. Dark areas in eastern De Long Mountains are dominantly underlain by chert, limestone, and mafic igneous rocks of the Ipnavik River allochthon. Areas outlined by thrust fault symbols are klippen of ophiolitic allochthons. IM — Iyikrok Mountain; AH — Avan Hills, MM — Misheguk Mountain, CP — Copter Peak, SM — Siniktanneyak Mountain. Mosaic by U.S. Geological Survey.

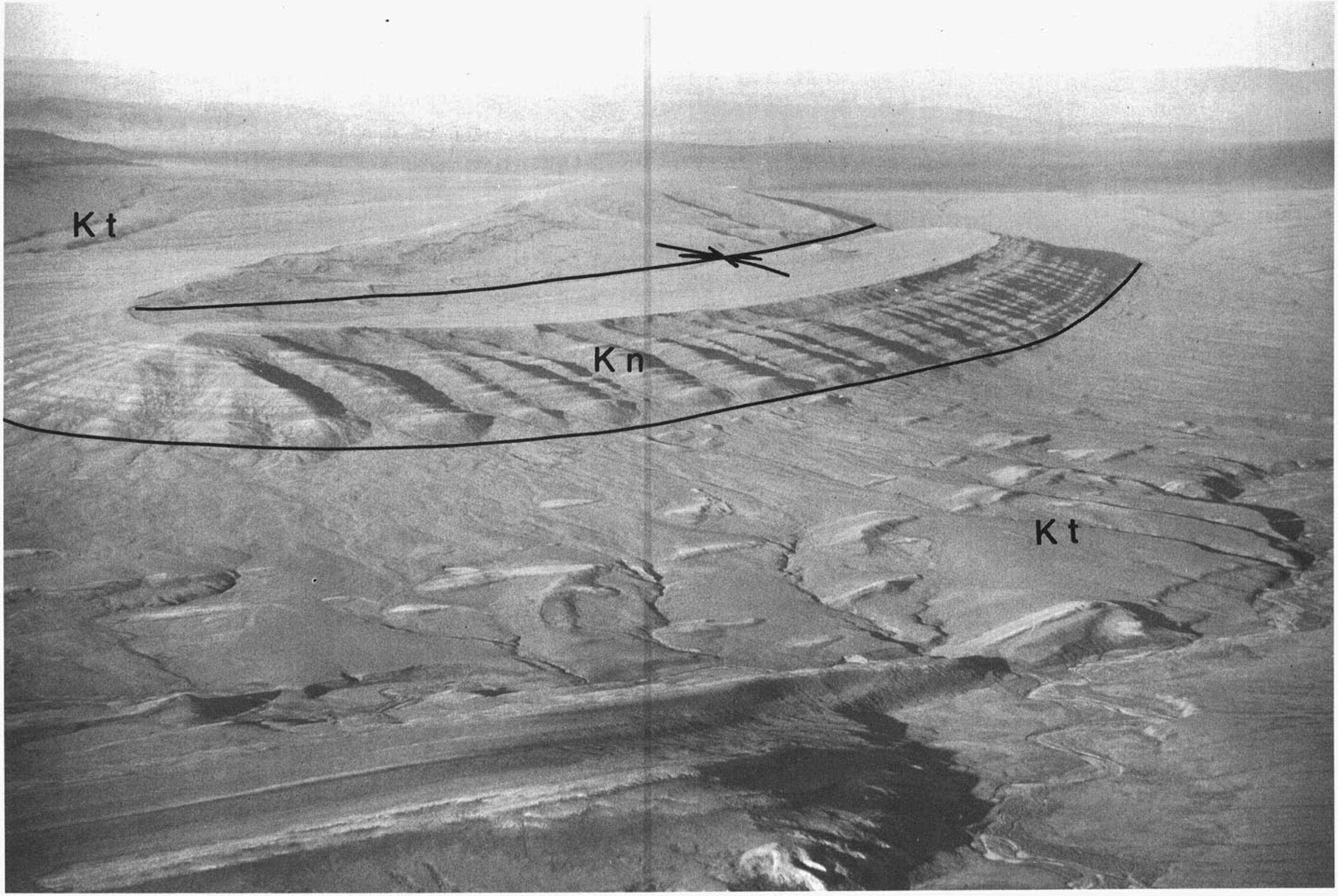


Figure 35. View northeast to Dugout syncline, northern De Long Mountains quadrangle. Resistant beds of Albian Nanushuk Group (Kn) are gently folded in décollement; Incompetent shale of Torok Formation (Kt) in valleys is generally complexly folded and is zone of detachment above which Nanushuk Group is folded independently of underlying Jurassic and older section. Length of syncline is approximately 15 km (9 mi).

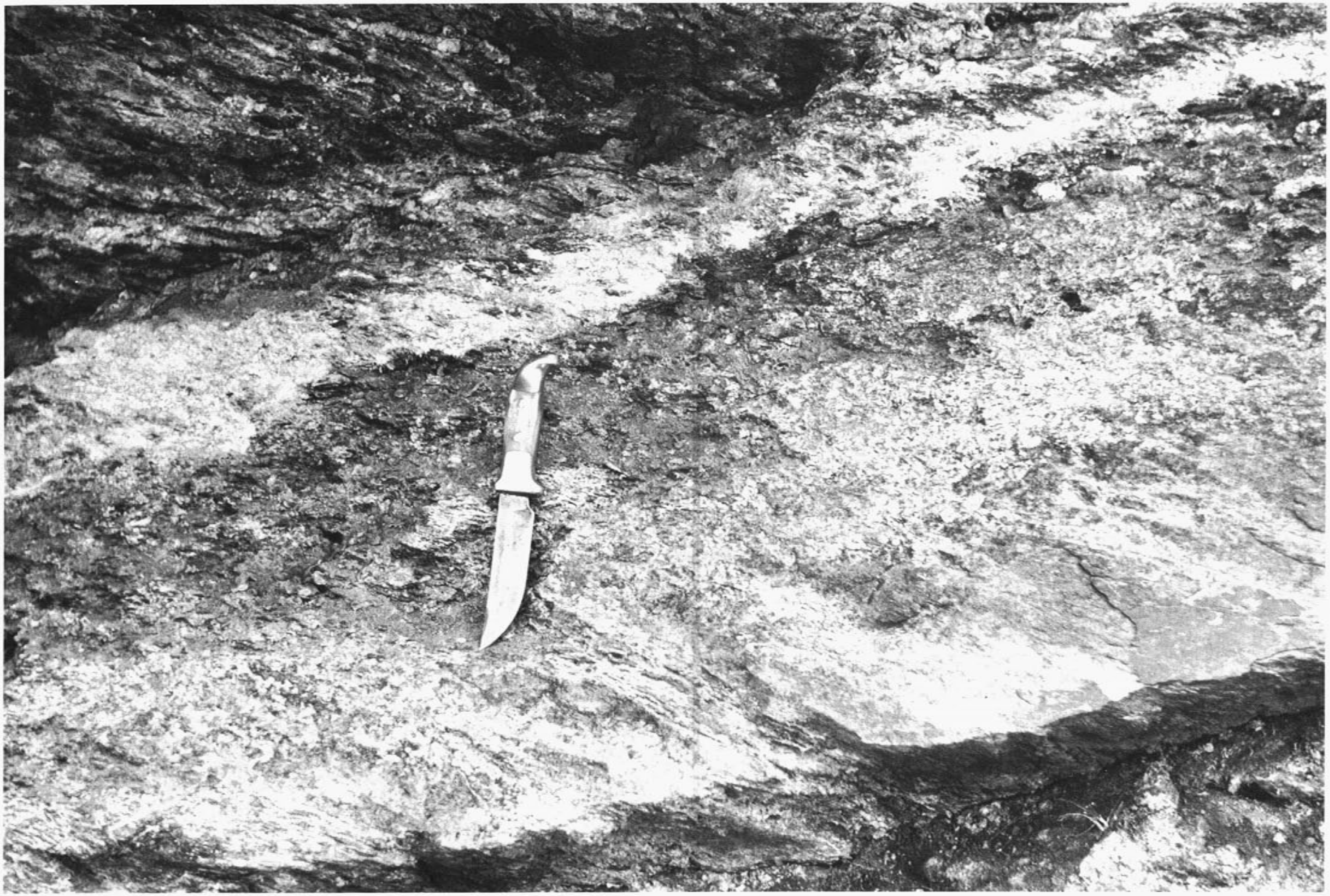


Figure 36. Closeup view of outcrop of Sadlerochit Group near Mt. Doonerak, northeastern Wiseman quadrangle. Bedding dips 15° to the north and cleavage dips 15-25° to the south suggesting relative northward transport of the overlying Endicott Mountains allochthon along the Amawk thrust fault (Fig. 20). Knife is seven inches long.

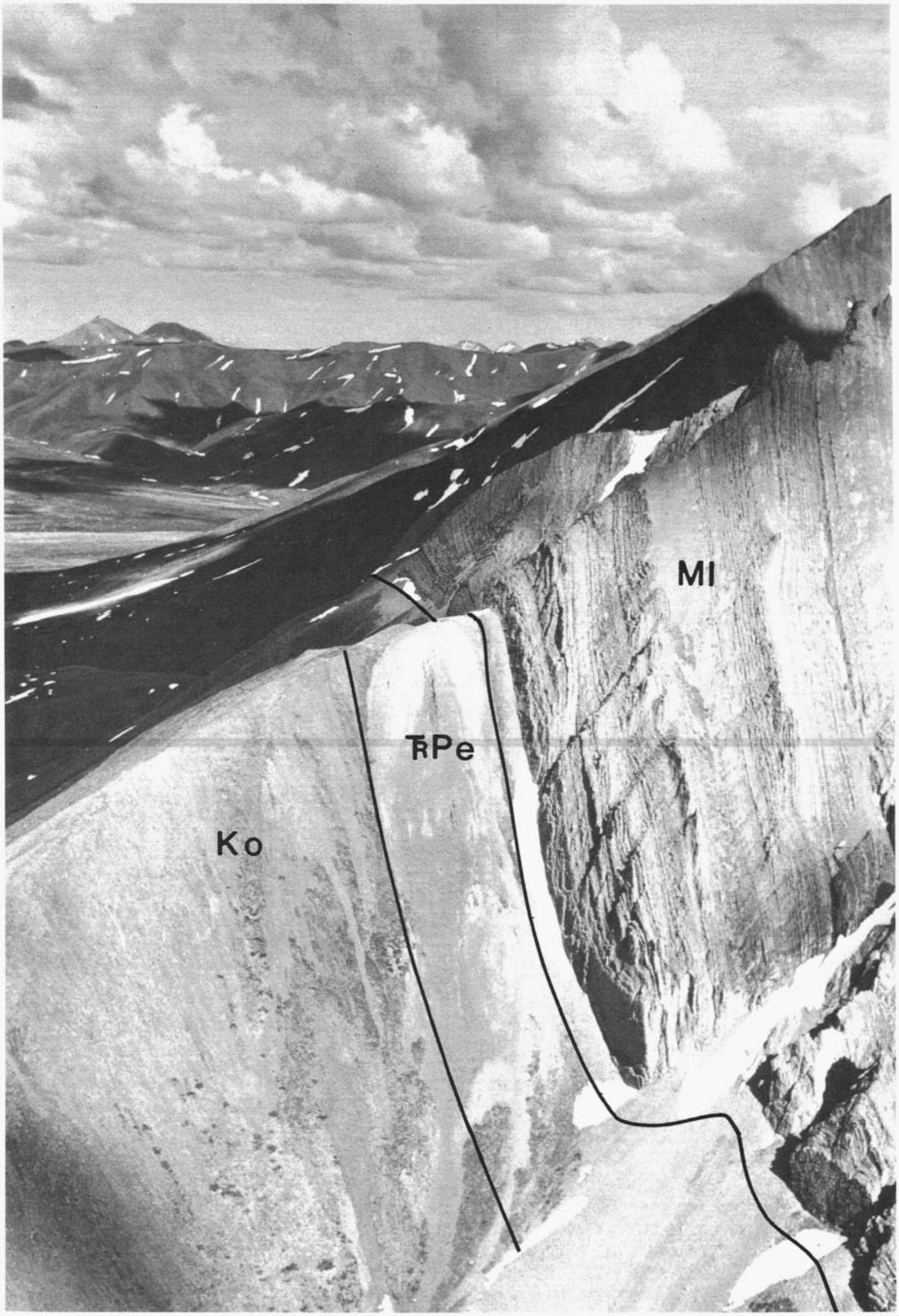


Figure 37. Eastward view of north flank of De Long Mountains near Kelly River, eastern De Long Mountains quadrangle. Lisburne Group limestone (Ml) stratigraphically overlying Etivluk Group siliceous shale and chert (T̄R Pe) and flysch of the Okpikruak Formation (Ko) on the Kelly River allochthon dip 70° to 90° N on the north flank of a regional anticline (to right, out of view). Minor slip along shear zones (mega-cleavage) in Lisburne dips 45° N and suggests relative northward tectonic transport of the Kelly River allochthon before regional folding. Topographic relief is 300 m (1000 ft).

Figure 38. View of olistostrome in western De Long Mountains, central De Long Mountains quadrangle. Large blocks of Mississippian limestone (ls) are encased in pebbly mudstone (mds) and overlain by a channel filled with boulder conglomerate (cgl). Note man for scale.

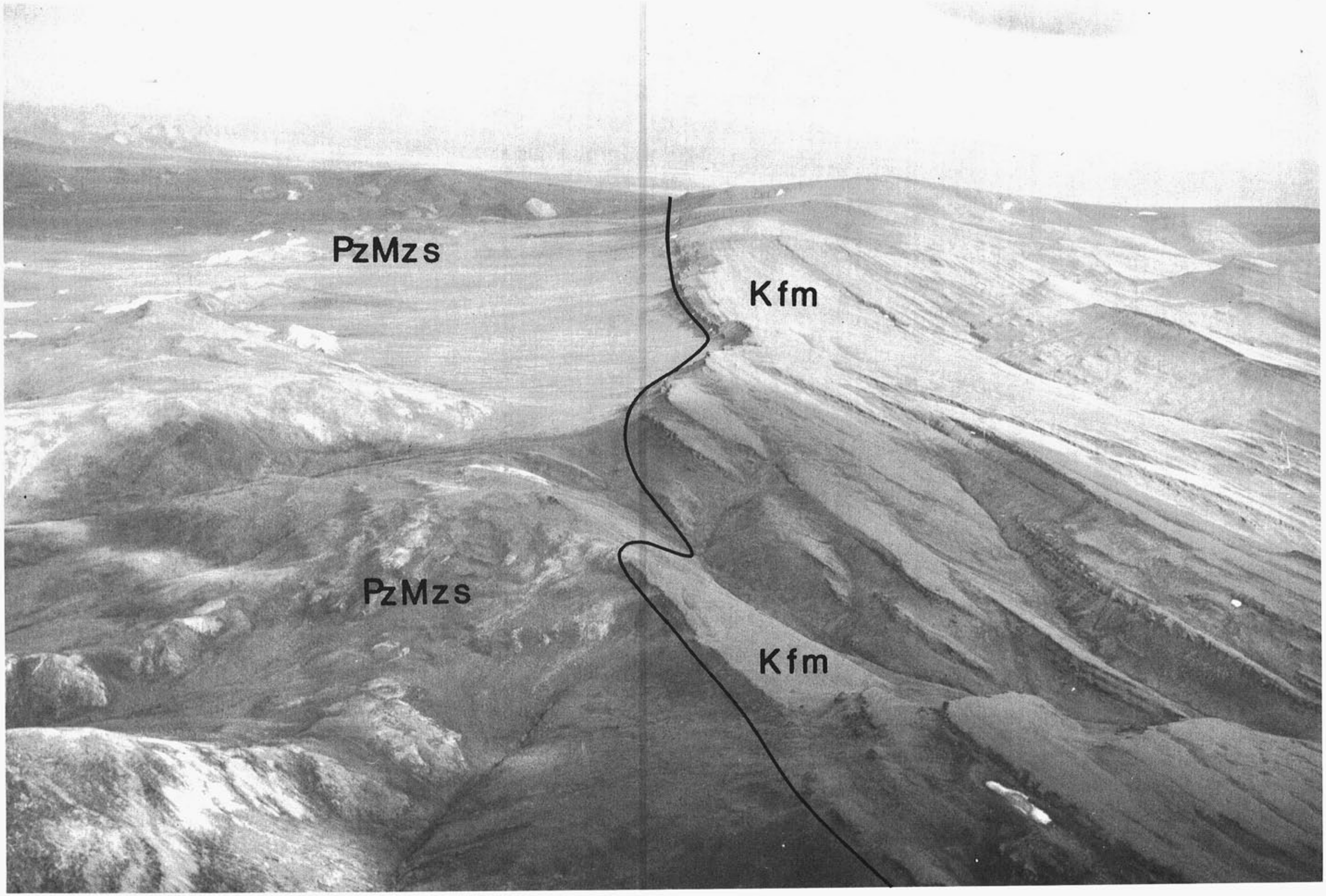


Figure 39. Southeastward view of Ekakevik Mountain, central Howard Pass quadrangle. Albian Fortress Mountain Formation (Kfm) dips 25° S and unconformably overlies tectonically slivered slices from Ipnavik River, Endicott Mountains and Nuka Ridge allochthons (Pz Mzs). Topographic relief is about 230 m (750 ft).

account the distance that would have separated the northern edge of an allochthon from the southern edge of the underlying allochthon prior to thrusting. In most cases, the contrast in facies of coeval rocks on superimposed allochthons requires an allowance for the rate of facies change from one sheet to the other in their original pre-thrusting basin position. There is insufficient detailed stratigraphic and structural control available to allow estimation of the magnitude intra-allochthon deformation and the distance necessary to account for facies changes between allochthons. It is clear, however, that an estimate of these two factors would greatly increase the estimate of shortening arrived at by only considering the amount of tectonic overlap. Calculated distances are thus minimum figures for shortening.

Minimum shortening for various areas in the Brooks Range is as follows:

Central De Long Mountains	580 km	(360 mi)
Western Endicott Mountains Section A-A′	450 km	(280 mi)
Central Endicott Mountains Section B-B′	269 km	(168 mi)
Eastern Endicott Mountains Section C-C′	56 km	(35 mi)
Eastern Brooks Range Section D-D′	96 km	(60 mi)

The data suggest a general decrease in the amount of crustal shortening eastward from the De Long Mountains. Many uncertainties exist in these calculations because absence of one major allochthon in an area due to post-emplacement erosion could unrealistically reduce the calculated distance of shortening in that area. Such could be the case in Section C-C′, in which no klippen of the mafic or ultramafic rocks remain north of the ophiolite trend at the southern margin of the range. However, regional geologic mapping and stratigraphic studies suggest that the ophiolitic allochthons were probably never emplaced along the mountain front of the eastern Endicott Mountains. Regionally, many conglomerate clasts from the Albian Fortress Mountain Formation can be matched with rocks of the allochthons from which the Fortress Mountain sediment was presumably derived. In the Chandler Lake quadrangle north of the central Endicott Mountains, conglomerate from the Fortress Mountain contains abundant clasts of mafic igneous rock. However, along the eastern Endicott Mountains front, thick Fortress Mountain conglomerate near the Atigun River contains no mafic igneous clasts. Clasts typical of other allochthons in the central Endicott Mountains are also absent in the Fortress Mountain of the Atigun River area. This evidence suggests that the absence of the structurally higher allochthons in the eastern Endicott Mountains area is the result of non-emplacement, rather than erosional stripping of the allochthons from the area.

Although they are subject to many uncertainties, these data suggestive of eastward decrease in amount of crustal shortening in the Brooks Range, provides evidence in support of the rotational hypothesis for the origin of the Canada basin of the Arctic Ocean proposed by Tailleur (1973) and supported by Rickwood (1970), Newman, Mull and Watkins (1977), and others. Approximately 70 degrees of counterclockwise rotation of the Arctic Alaska plate about a pivot in the general area of the Mackenzie River delta has been suggested. Compressional shortening along the leading edge of such a rotating block would be expected to decrease toward the rotational pivot. Although the rotational hypothesis is favored here, it is controversial and is not a unique explanation for the regional geology of northern Alaska. The subject is beyond the scope of this discussion, but has been summarized by Nilsen and others, (1982).

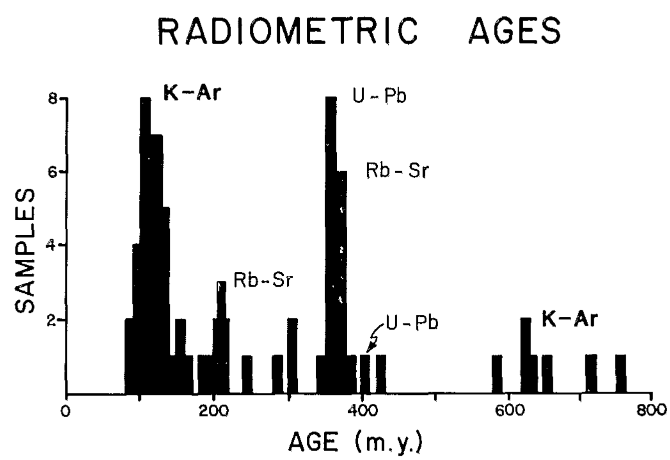
SEQUENCE OF BROOKS RANGE DEFORMATION

Dating of the development of the Brooks Range orogenic belt is well controlled by stratigraphic evidence. Early Cretaceous (Neocomian) flysch is widespread on most of the allochthons of the central and western Brooks Range; in some areas the thickness in outcrop has been suggested to be as much as 1800 m (5,900 ft) (Sable and Mangus, 1950). Discontinuously associated with the typical rhythmic turbidites of the flysch sequence is massive chaotic boulder conglomerate that can be described as wildflysch or an olistostrome (Fig. 38). Identifiable boulders and exotic blocks derived from all of the major allochthons, including the ophiolitic allochthon, are found within these deposits. Sedimentation of this type suggests that the major allochthons of the Brooks Range had been telescoped in a terrane with major topographic relief by the end of the Neocomian, approximately 115 m.y.

At several locations in the foothills of the Endicott Mountains, tectonically telescoped and slivered allochthons are unconformably overlain by gently folded early Albian conglomerate (Fig. 39, see mapping by Tailleur and others, 1966). This relationship suggests that in the Endicott Mountains major crustal shortening had ended by the Albian. On the north side of the De Long Mountains, however, flysch of Albian age seems to have been telescoped by thrust faults and suggests that thrust deformation continued later in the western Brooks Range than to the east.

Radiometric dating from the schist belt and plutons of the Brooks Range also provides control on the age of deformation (Fig. 40). A cluster of U-Pb and Rb-Sr dates around 360 to 370 m.y. (Late Devonian) coincides with the deposition of the clastic wedge of the Kanayut Conglomerate and Hunt Fork Shale and is probably related to the Innuitian orogeny of Arctic Canada. A cluster of K-Ar dates ranges from 90 to 130 m.y., with a peak at 100 to 110 m.y. Some of these dates are from the same bodies yielding Devonian U-Pb and Rb-Sr dates and suggest resetting of the K-Ar clock during the Cretaceous orogeny. The peak of K-Ar dates may coincide with the period of dominantly vertical uplift in the core of the range.

Objections have been raised to the interpretation of allochthon emplacement by crustal compression north of the core of the range. These objections suggest that it is difficult to en-



(Modified from Turner, Forbes, and Dillon, 1979)

Figure 40. Radiometric dates from Brooks Range. K-Ar dates from Turner, Forbes and Dillon (1979); U-Pb dates from Dillon and others (1980); Rb-Sr dates from Silberman and others (1979). Dates are K-Ar unless otherwise indicated.

vision crustal compression thrusting major allochthons over the core of the range. Gravitational gliding has been suggested as the mechanism for emplacement of the allochthons along the north front of the Endicott and De Long Mountains. However, the interpretation of the sequence of events favored here removes these objections because the uplift of the core postdates the period of dominant horizontal compression. However, late stage northward gravitational gliding of allochthons initially emplaced by crustal compression may have occurred as a consequence of the sequence of deformational events favored here. Such deformation, superimposed over the deformation by crustal compression, may accentuate the apparent magnitude of crustal shortening and further complicate the structural interpretation.

In contrast to the dating of the central and western Brooks Range deformation, the northward salient of the northeastern Brooks Range appears to have had a younger deformational history. Stratigraphic evidence suggests post-Albian uplift of the northeastern Brooks Range. North of the Endicott Mountains, facies trends in the Albian molassoid rocks are approximately parallel with the mountain front, but in the area of the Atigun and Sagavanirktok River, where the mountain front begins to trend northeastward, the Albian facies trends and mountain front converge. West of the Sagavanirktok River the Fortress Mountain Formation typically contains thick beds of boulder conglomerate, and the Nanushuk Group consists of a coal bearing nonmarine delatic complex. In contrast, coeval Albian facies along the mountain front northeast of the Sagavanirktok River consist entirely of marine turbidites, indicative of submarine fan deposition at a much greater distance from a sediment source than represented by Albian facies to the west.

In the Kavik and Shaviovik River area of the northeastern Arctic Slope possible nonmarine or shallow marine conglomeratic sandstone is correlative with the Kogosukruk Tongue of the Prince Creek Formation. The Kogosukruk is considered to be Campanian or younger (Brosgé and Whittington, 1975) and its presence on the northeastern Arctic Slope is suggestive of Late Cretaceous tectonic activity in the northeastern Brooks Range. In the Arctic National Wildlife Refuge, identical facies of both the Neocomian Kemik Sandstone Member of the Kongakut Formation and the Late Cretaceous Colville Group crop out on both sides of the Sadlerochit Mountains, and indicate that uplift of this portion of the northeastern Brooks Range did not begin before the Tertiary.

The area of post-Albian uplift coincides with the area of dominantly vertical basement involved uplift of the northeastern Brooks Range illustrated in Section D-D′. These relationships highlight the fundamental contrast in structural style along the Brooks Range mountain front: Late Cretaceous and Tertiary vertical uplift of autochthonous rocks of the northeastern Brooks Range east of the Sagavanirktok River and Trans-Alaska pipeline, in contrast to the Early Cretaceous extreme crustal shortening and telescoping of facies along the central and western Brooks Range mountain front.

SUMMARY OF BROOKS RANGE TECTONICS

Regional data summarized and illustrated above results in an inferred sequence of major tectonic events summarized in Figure 41. Plate movement during the Neocomian is inferred to have resulted in obduction of oceanic crust over continental crust and formation of a major thrust belt at the southern edge of the Arctic Alaska plate.

Radiometric dating and structural style, with the allochthons dipping northward off the core of the range, suggest that dominantly vertical uplift of the core occurred during the Albian and Late Cretaceous, following emplacement of the allochthons. Major regional folding and refaulting of the central and western Brooks Range allochthons is inferred to have accompanied the core uplift (Fig. 41). This uplift of the core can be in-

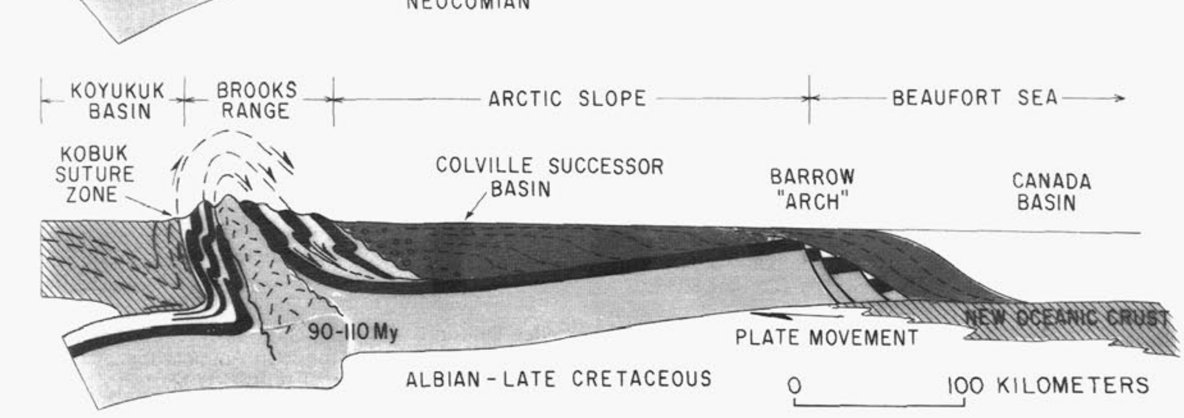


Figure 41. Inferred sequence of tectonic events in evolution of Brooks Range, Arctic Slope, and Beaufort Sea continental margin. Granite in core of range is Devonian age with K-Ar date reset during the Cretaceous orogeny.

terpreted to be the result of isostatic rebound of continental crust that was deeply depressed beneath the obducted ophiolitic allochthons during the stage of Neocomian crustal shortening.

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