Public-data File 89-1a

PRELIMINARY GEOLOGY OF THE PRE-MISSISSIPPIAN ROCKS OF THE AICHILIK AND EGAKSRAK RIVER AREAS, NORTHEASTERN BROOKS RANGE, ALASKA

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Alaska Division of
Geological and Geophysical Surveys

February 1989

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Abstract

The range front in the northeastern part of the Arctic National Wildlife Refuge is defined by an anticlinorium cored by carbonate and siliciclastic rocks of the pre-Mississippian Franklinian sequence, with Mississippian through Triassic rocks of the Ellesmerian sequence defining its northern and southern limbs. Field relationships suggest deformation of both the carbonate and siliciclastic rocks of the pre-Mississippian sequence occurred in a north-vergent fold and thrust belt, probably during pre-Mississippian time. These structures were then truncated by the pre-Mississippian unconformity at the base of the Ellesmerian sequence, and depositionally overlain by the Mississippian Kekiktuk Conglomerate.

The pre-Mississippian structures were later reactivated during formation of the anticlinorium in Cenozoic time. During this deformation, the pre-Mississippian rocks were imbricated in a regional duplex, between a roof thrust in the Mississippian Kayak Shale, and a floor thrust at depth. The Mississippian and younger rocks overlying the Kayak Shale deformed separately by a combination of thrust duplication and detachment folding. However, the Kekiktuk Conglomerate was below the roof detachment, and behaved structurally as part of the underlying pre-Mississippian sequence. Reactivated pre-Mississippian thrust faults truncated and displaced these basal conglomerates, cutting up-section and flattening in the detachment in the overlying Kayak Shale. The transport direction during Cenozoic deformation was probably to the northwest.

New paleontologic data from potentially correlative pre-Mississippian rocks in the Canadian Yukon (Lane and Cecile, 1989) suggests that many of the pre-Mississippian rocks of northeastern ANWR are early Paleozoic in age. They may have been deposited in a basinal environment with localized carbonate and volcanic highs. North-vergent thrusting during pre-Mississippian time collapsed the basin, resulting in the regional northward older-over-younger relationships still preserved within the pre-Mississippian sequence.

Introduction

The Brooks Range is a Late Jurassic to Early Cretaceous fold and thrust belt that extends from the Canadian border west to the Chukchi Sea and on into northeastern Siberia. The northeastern Brooks Range is a northern salient with respect to the main axis of the Brooks Range and consists of a Cenozoic fold and thrust belt that incorporates para-autochthonous rocks equivalent to those of the North Slope (figures 1 and 2; Reiser, 1970). The dominant structural style of the region consists of 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 thrusts at depth in the pre-Mississippian rocks (Namson and Wallace, 1986; Wallace and Hanks, in review). The structural behavior of the pre-Mississippian rocks during formation of the anticlinoria is unclear, and is the focus of several projects in progress.

This report documents preliminary results of a traverse through the pre-Mississippian rocks in one of these anticlinoria, and offers some speculations on both the pre-Mississippian and Cenozoic behavior of the pre-Mississippian rocks during the structural evolution of the region. The study area transects the northernmost anticlinorium of Demarcation Point quadrangle between the Aichilik and Egaksrak Rivers; figure 1), and is part of a University of Alaska Ph.D. dissertation on the structural evolution of the range-front region of northeastern ANWR.

Regional Setting

Pre-Mississippian stratigraphy

The stratigraphy of the pre-Mississippian rocks of the northeastern Brooks Range and their relationship to potentially correlative strata in Canada and the rest of the circum-Arctic region is poorly understood. Leffingwell (1919) first defined a pre-Mississippian unit, a quartzose sandstone/semischist, as the Neruokpuk Formation. This terminology was later expanded to include most of the pre-Mississippian sequence. Stratigraphic studies (Brosgé and others, 1962; Dutro, 1970; Dutro and others, 1972; Moore and Churkin, 1984) have determined that at least a part of the sequence in the Franklin Mountains and Demarcation Point quadrangle is Cambrian to Ordovician in age. Recent stratigraphic studies in the Sadlerochit and Shublik Mountains (Blodgett and others, 1986) have determined that the Nanook Limestone is also Cambrian through Devonian in age.

Reiser and others (1980) described the apparent stratigraphy of the pre-Mississippian rocks in Demarcation Point quadrangle. In this stratigraphy, the unfossiliferous limestones and shales that make up the majority of the core of the northern anticlinorium (Aichilik River anticlinorium; figure 1) were considered pre-Cambrian in age, possibly because they structurally underlie sandstones and limestones dated by trilobite and echinoid debris as Lower Cambrian in age (Reiser and others, 1980). The unfossiliferous limestones in turn structurally overlie siltstones that Reiser and others considered correlative with graptolite-bearing Ordovician shales near the U.S.A./Canada border.

Current work by the Geological Survey of Canada immediately east of the U.S./Canadian border in the northwestern Yukon Territory suggests that the lower Paleozoic stratigraphy of the western Canadian Cordillera extends into that region (Lane and Cecile, 1989). Mapping by Reiser and others (1980) and Norris (1984) suggest that these lower Palezoic rocks are, in part, laterally equivalent to the pre-Mississippian rocks of the northern anticlinorium of Demarcation Point quadrangle. This correlation suggests that the pre-Mississippian rocks in this part of the northeastern Brooks Range may also be of lower Paleozoic age and not pre-Cambrian.

Pre-Mississippian rocks in the northeastern Brooks Range are also commonly referred to as the 'Franklinian Sequence' (Lerand, 1972). Use of this terminology implies a correlation between these rocks and lower Paleozoic and upper pre-Cambrian rocks of the Franklinian geosyncline of the Canadian Arctic Islands. The stratigraphy of the Franklinian geosyncline in that area is reasonably well understood (for ex., Trettin, 1971; 1979), but stratigraphic correlations between the Canadian Arctic Islands and northeastern Alaska have not been firmly established.

Deformation of the pre-Mississippian rocks

Cenozoic deformation

Recent regional and detailed structural studies suggest that the anticlinoria of the northeastern Brooks Range are the result of Cenozoic thrusting (Leiggi, 1987; Rattey, 1985; Namson and Wallace, 1986; Kelley and Foland, 1987). The geometry of the anticlinoria, especially in the western part of ANWR, suggest that they formed above a regional, shallow-crustal duplex, with imbrication of pre-Mississippian rocks between a floor thrust at depth and a roof thrust in the overlying Mississippian Kayak Shale, and (Namson and Wallace, 1986). The fact that the pre-Mississippian unconformity displays a fault-bend fold geometry, and that little imbrication of the Mississippian Kekiktuk Conglomerate has been observed suggests to some workers (Wallace and Hanks, in review) that there has been little penetrative deformation of the pre-Mississippian rocks during the Cenozoic formation of the anticlinoria, with most of the shortening having been accommodated by the regional duplex. However, similarities in the trends of the latest penetrative fabrics in the pre-Mississippian rocks with those in the overlying Kayak Shale suggest to other workers (Oldow and others, 1987) that the pre-Mississippian rocks were penetratively deformed during Cenozoic deformation.

Several lines of evidence indicate that the youngest deformational event is Cenozoic in age.

Although the youngest preserved rocks involved in the formation of the anticlinoria of eastern ANWR are middle Cretaceous in age (Bathtub Ridge, Reiser and others, 1980), Paleogene rocks were involved in this deformational event in western ANWR (Reiser and others, 1971, 1980; Kelley and Foland, 1987; O'Sullivan, 1988). Cretaceous and Early Tertiary sediments of the ANWR coastal plain deposits were also deformed in middle Tertiary time, as indicated by a major Eocene unconformity in the subsurface (Kelley and Foland, 1987; Bruns and others, 1987). Deformation of the Eocene unconformity itself suggests that there has been even younger deformation.

Recent apatite fission-track uplift studies in ANWR also suggest that there were major periods of uplift during Early Paleocene and Early Eocene time (O'Sullivan, 1988). In addition, conventional K/Ar ages from the Devonian Jago Stock to the west suggest an uplift event approximately 60 mybp (Dillon and others, 1987). Both these indirect lines of evidence suggest that the anticlinorium and related structures formed during Early Tertiary time.

Pre-Mississippian deformation

The existence of the angular unconformity between the pre-Mississippian rocks and overlying Mississippian and younger rocks of the Ellesmerian sequence have led most workers in the region to agree that there was a Devonian or older deformational event (Reed, 1968; Sable, 1977; Reiser, 1970). The number of pre-Mississippian events and their style and sense of vergence are however, uncertain. Regionally, exposed pre-Mississippian rocks are mainly upright and south-dipping with respect to the overlying unconformity surface. In the subsurface of the North Slope, seismic reflectors within the pre-Mississippian sequence are also south-dipping (Hubbard and others, 1987). Both of these observations have been interpreted as evidence of pre-Mississippian north-vergent thrusting. However, detailed mesoscopic and microscopic data in local areas in the Franklin Mountains by Oldow and others (1987) suggest that at least one event during pre-Mississippian time was south-vergent.

Resolution of the nature and vergence of pre-Mississippian deformational events is hampered in northeastern ANWR by the general inaccessibility and poor exposure of both the pre-Mississippian rocks and the unconformity surface, by the lack of a known stratigraphy within the pre-Mississippian sequence, and by the extreme lithologic heterogeneity of the pre-Mississippian sequence. This heterogeneity results in highly variable development of mesoscopic structures in different lithologies due to varying mechanical behavior.

Purpose and Area of Study

The purpose of this study is to determine the manner in which the pre-Mississippian rocks have been involved in the development of one of the regional anticlinoria, the Aichilik River anticlinorium. Specifically, what structures now visible in the pre-Mississippian sequence are of pre-Mississippian age? Which structures can be demonstrated to be related to the Cenozoic formation of the anticlinorium? What is the local pre-Mississippian stratigraphy, and how does it reflect both pre-Mississippian and Cenozoic structures? The study area transects the pre-Mississippian rocks of the Franklinian sequence and Mississippian and younger rocks of the Ellesmerian sequence of the Aichilik River anticlinorium between the Aichilik and Egaksrak Rivers (Demarcation Point quadrangles B3 and B4, figure 1).

Stratigraphy

Pre-Mississippian rocks

In this part of the anticlinorium, the pre-Mississippian sequence consists predominantly of two distinctive packages–a carbonate sequence to the north, and a siliciclastic sequence to the south (see map and cross section E-E'; figure 3). The carbonate succession consists primarily of thick, massive black limestones and dolomites (bl) which appear to overlie, but may also interfinger with, rippled sandy limestones/limy sandstones (rl) and brown argillites (ba). In the study area, 'rl' dominates in the north while 'bl' is more extensive in the central parts of the anticlinorium. The total thickness of the entire carbonate succession appears to vary greatly, probably due both to stratigraphic variations and structural complexities, but may be as much as 1000 meters or more in the study area.

In the northern part of the study area, and to the east on Redwacke Creek (Reiser and others, 1980), this carbonate sequence overlies a red-weathering volcaniclastic (?) sandstone (rss). It is not clear if this contact is depositional or structural in nature.

In the southern part of the anticlinorium, the carbonate succession is structurally overlain by a dominantly siliciclastic sequence (see map). This clastic succession is dominated by a thick package of quartz-lithic sandstones and scattered chert-granule conglomerates (qs). These sandstones are generally well-bedded and highly rippled, with interbeds of maroon and tan siltstones. Feeding trails and burrows are preserved on the bedding surfaces of these siltstones. The sandstone package appears to be underlain by a distinctive bedded chert with interbeds of shale and maroon rippled sandstone (qa) and a heterogeneous package of siltstones, shales and rippled sandy limestones (bs). The sandstone unit ('qs') is overlain by a thick succession of gray, black and white bedded cherts (ch).

The relationship of this sandstone succession to the clastic rocks exposed on the northern flank of anticlinorium to the south is unclear ('css', 'lss' and 'ps', enclosed map). These latter rocks are considered Early Cambrian in age based on echinoid debris found in one location south of the study area, and Cambrian trilobites from a limestone at the base of the structurally overlying Whale

Mountain Volcanics (Reiser and others, 1980). This sandstone succession is more calcareous than the sandstone succession to the north ('qs'), and contains thick intervals of black shale. However, cherts similar to those of 'ch' and maroon siltstones similar to those associated with 'qs' are also associated with these more calcareous clastic rocks, although the nature of the relationship is not clear. Many of the apparent difference between the two clastic successions could be due to facies changes.

Mississippian through Triassic rocks

Both the northern and southern flanks of the anticlinorium in the study area are defined by Mississippian through Triassic rocks of the Ellesmerian cover sequence (see map and cross section E-E'). The stratigraphy of these rocks is essentially that of age-equivalent rocks of the North Slope subsurface, with lithologic variations due to facies changes (figure 2; Reiser, 1970). The base of this sequence is a siliciclastic succession, the Mississippian Endicott Group (Meu, Mkk, Mes, Mel), which is abruptly overlain by the Mississippian and Pennsylvanian Lisburne Group, a regionally extensive and complex carbonate platform sequence (Ma, MPw). This carbonate platform sequence is in turn abruptly overlain by the Permo-Triassic Sadlerochit Group, a complex clastic succession derived from the north (TrPs, Trkc).

Structure

Pre-Mississippian rocks

The pre-Mississippian rocks are highly deformed at both map and mesoscopic scale, with lithology and competency contrasts having a strong influence on their structural style. The map-scale structures of the carbonate sequence are characterized by north-vergent folds and thrust faults in the more rigid units ('bl') above a detachment in an underlying shale ('ba') (cross section E-E'). The depth-to-detachment for these particular fold-and-thrust structures is approximately 1 km below the surface, based on the relatively thin nature of entire carbonate sequence (< 1 km).

The map-scale deformational style of the siliciclastic sequence is less clear because it is poorly exposed in the study area. Some structural repetition of the sandier portions of the sequence ('qs') can be seen immediately north of the southern flank of the anticlinorium (see cross section E-E'), suggesting that the main sandstone interval ('qs') has deformed above a detachment in a more shaly horizon ('bs').

Both the carbonate and siliciclastic sequences are highly deformed at a mesoscopic scale. Most of this small-scale deformation is localized in the finer-grained and thinner-bedded units. Both sequences exhibit at least two generations of structures.

The first deformational event (D1) is represented by a micaceous foliation and/or pervasive cleavage that is commonly well-developed in the siltstones and shales of both the siliciclastic and carbonate sequences. This surface is generally sub-parallel to bedding and south-dipping, although some steeply north-dipping S1 surfaces are present in the southern half of the anticlinorium where bedding is also steeply north-dipping. Locally, the massive limestones of 'bl' have a poorly developed dissolution cleavage, but generally have several generations of calcite-filled fractures, probably related to both D1 and D2, although those relationships are presently unclear. In the stereoplots (figures 4 & 5), both bedding and the S1 surfaces in the carbonate and siliciclastic sequences appear to be folded about east-trending subhorizontal fold axes. This folding may be related to both the north-vergent folds and thrusts seen at map scale and mesoscopic folds within 'ba', 'rl' and 'bs'. The development of the girdle defined by poles to both bedding and S1 may have been enhanced by progressive regional steepening of both bedding and S1 surfaces as the fold and thrust belt migrated northward.

Structures related to the second deformational event (D2) are less well-defined and are generally localized in shales of both the carbonate and siliciclastic sequences. S2 generally is defined by a spaced slaty cleavage and/or an anastomosing semi-pervasive shear surface. The spaced slaty cleavage is often associated with mesoscopic open folds (F2), while the shear surfaces generally post-date mesoscopic open and tight folds, suggesting that the folds formed either late during D1 or early during D2. Both types of S2 surfaces generally strike ENE, and dip moderately to the south (figure 6). Plots of S2 data suggest that this surface has been folded about SSW-trending subhorizontal to moderately plunging fold axes. However, this deformation does not appear to have reoriented bedding or S1 fabrics throughout the study area (figures 4 & 5) and may be localized to detachment horizons in certain locations. An exception is in the footwall of a Cenozoic thrust in the northern half of the study area (section 33 of map, cross section E-E') where bedding has been totally reoriented by D2 shearing (figure 7). As with S1, the apparent open folding of S2 could be due to either localized mesoscopic late D2 folding within detachment horizons, or rotation and steepening of S2 during later thrusting.

Mississippian and younger rocks

The Mississippian and younger rocks of the Ellesmerian sequence define the northern and southern limbs of the Aichilik River anticlinorium. The Mississippian Kayak Shale has acted as a major detachment horizon on both limbs, permitting the overlying limestones of the Lisburne Group and siliciclastic rocks of the Sadlerochit Group to deform independently of the underlying pre-Mississippian rocks. Where exposed, the Kayak Shale is commonly highly deformed and structurally thickened, with tight to isoclinal mesoscopic folds and a related slaty cleavage. Deformation is particularly strong where Cenozoic thrust faults have cut up-section from the pre-Mississippian rocks and flattened in the Kayak Shale (for example, sections 32 & 33 of map, cross section E-E'). Where this has occurred, structures within the deformed Kayak Shale generally trend ENE, suggesting a NNW direction of tectonic transport (figure 8).

The Mississippian Kekiktuk Conglomerate lies depositionally directly on the pre-Mississippian sequence, and is displays considerable lateral variation in both thickness and facies. However, it underlies the Kayak Shale detachment horizon, and thus has deformed with the pre-Mississippian sequence during Cenozoic formation of the anticlinorium (cross section E-E'). Depending upon its structural position (ie., whether it is in the footwall or hanging wall), lithology, and the lithology and degree of D2 deformation within the underlying pre-Mississippian sequence, the Kekiktuk can vary from undeformed to mildly deformed, as indicated by extension fractures, slightly stretched pebbles or a spaced semi-pervasive cleavage. Deformation within the Kekiktuk appears to be the greatest in the footwall of Cenozoic thrusts and where it is thin and shaly. In all instances, however, the pre-Mississippian rocks are more highly deformed and show more mesoscopic shortening than does the immediately overlying Kekiktuk Conglomerate.

Above the Kayak Shale, the massive limestones of the Mississippian and Pennsylvanian Lisburne Group have acted as the main structurally competent interval of, and have controlled the style of deformation in, the overlying Ellesmerian sequence. In the study area, the Ellesmerian sequence above the Kayak Shale has been shortened primarily by large-scale thrust duplication of the entire Ellesmerian sequence (exclusive of the Kekiktuk Conglomerate) and secondarily by minor detachment folding, both by detachment of the Ellesmerian sequence above the Kayak Shale (cross section E-E'). Minor detachment folding also occurs within the Sadlerochit Group due to detachment along several thick shale horizons. Both the allochthonous Ellesmerian sequence rocks of the thrust sheet and the underlying para-autochthonous Ellesmerian sequence rocks display ENE-trending structures (figure 9 and enclosed map).

Discussion

Involvement of pre-Mississippian rocks in Cenozoic formation of the Aichilik River anticlinorium

On a regional scale, the Aichilik River anticlinorium was formed by Cenozoic duplexing of the pre-Mississippian rocks between a floor thrust at depth and a roof thrust in the Kayak Shale. At present, the thickness, length and width of these horses within the duplex is not known, but they must be of considerable size (kms) in order to accommodate the depth to detachment as inferred from seismic data to the north (U.S. Dept. of the Interior, 1987), assuming that there is one primary basal detachment. Because the pre-Mississippian rocks form the core of the Cenozoic anticlinorium, they have obviously been involved in both pre-Mississippian and Cenozoic deformational events, but the relative contribution of these two events to the overall shortening within the pre-Mississippian sequence is difficult to ascertain. This is due largely to the fact that the pre-Mississippian unconformity and the overlying Mississippian Kekiktuk Conglomerate have been eroded throughout most of the area. It is difficult, therefore, to evaluate which of the structures predate and which post-date the unconformity.

In both the northern and southern parts of the study area, the Kekiktuk Conglomerate has been imbricated with the pre-Mississippian rocks (for ex., enclosed map T2N, R38E, S33; T1S, R39E, S9 & 10), implying that at least some of the deformation in the pre-Mississippian rocks post-dates the pre-Mississippian unconformity. In these areas, S2 fabrics are commonly well-developed and locally have totally disrupted and reoriented the pre-Mississippian rocks in the footwall of the thrusts. However, even in these areas, the amount of shortening in the pre-Mississippian rocks far exceeds that in the Mississippian Kekiktuk Conglomerate, as indicated both by mesoscopic structures and the amount of apparent Cenozoic displacement of the Kekiktuk Conglomerate vs that of the pre-Mississippian rocks along the same thrust fault.

Trends of the mesoscopic structures also suggest that structures formed during a pervasive pre-Mississippian deformational event were reactivated during a Cenozoic deformation. The Cenozoic deformational trend strikes ENE, as indicated by bedding, mesoscopic structures and map-scale structures, suggesting a NNW transport direction (figures 8 & 9, map). NNW transport directions during Cenozoic deformation of the Ellesmerian sequence rocks are also suggested by minor tear and thrust faults along Leffingwell Ridge (see map). Some pre-Mississippian rocks associated with Cenozoic thrusts have been reoriented into this new direction, possibly via small-scale imbrication (figure 7); in other areas, S2 fabrics display ENE trends (figure 6).

However, the vast majority of the pre-Mississippian rocks in the study area show little evidence of the Cenozoic ENE trends. To the contrary, the structural data from the pre-Mississippian rocks generally displays EW trends (figures 4 & 5). This mesoscopic data in conjunction with the observed map-scale structures suggest that the pre-Mississippian rocks were deformed by north-directed thrusting and related folding during pre-Mississippian time. The main Cenozoic affect, if any, on these early structures may have been reactivation and tightening of some of the structures.

Regional pre-Mississippian paleogeography and structure--some speculations

The discovery of Cambrian through Silurian fossils and trace fossils in the northwestern Yukon Territory by L. Lane and M. Cecile (1989) raises the possibility that rocks in northern Demarcation Point Quadrangle previously considered to be pre-Cambrian in age (Reiser and others, 1980) may actually be of lower Paleozoic age. Assuming this correlation is correct, it is possible to reconstruct a pre-Mississippian paleogeography and regional stratigraphic framework. Such a broad paleogeographic reconstruction must explain both the lateral changes in lithology within the pre-Mississippian rocks and the apparent regional northward older-over-younger relationships still preserved within the pre-Mississippian sequence of Demarcation Point quadrangle (Reiser and others, 1980).

A speculative reconstruction of the regional stratigraphy of the northeastern Brooks Range during early Paleozoic time is illustrated in figure 10. This stratigraphy is based on known ages within the pre-Mississippian sequence (for ex., Brosgé and others, 1962; Dutro, 1970; Dutro and others, 1972; Blodgett and others, 1986; Reiser and others, 1980), the new Canadian age data (Lane and Cecile, 1989) and the present regional distribution of major lithologic units within the pre-Mississippian sequence. This reconstruction suggests that, during the early Paleozoic, the present northeastern Brooks Range was a starved basin. In the northwest, the Nanook Limestone of the Sadlerochit and Shublik Mountains represents a long-lived carbonate platform that had existed since the pre-Cambrian. This carbonate platform could represent either an isolated high in the starved basin, or a continental margin to the north (present coordinates). The platform would have served as a source for periodic carbonate turbidites, now represented by the thick pre-Mississippian limestones of northwestern Demarcation Point quadrangle ('bl'). The rippled sandy limestones/limy sandstones ('rl') that underlie and interfinger with these limestone turbidites may represent a shallower-water and/or slope facies for the turbidite system. Both of these lithologies gradually become less dominant and possibly even disappear to the east and southeast with increasing distance from the carbonate platform, and are replaced by the cherts and shales of the starved basin proper.

To the south, clastic deposition dominated in pre-Cambrian to Early Cambrian time ('qs', 'css', 'lss'), with the local development of a volcanic complex (the Whale Mountain volcanics) during late Early Cambrian time. This volcanic complex contributed volcaniclastic debris to the surrounding basin ('rss'), possibly contributing to some volcanogenic chert development as well. The upper age limit of these volcanics is presently unconstrained except that they must predate the pre-Mississippian unconformity at the base of the Ellesmerian sequence.

Other than the two localized highs and potential sediment sources represented by the Nanook limestone and the Whale Mountain Volcanics, the basin was starved and contained mainly deep-marine basinal deposits. This basic depositional pattern continued until Early Devonian, when these rocks were deformed and unconformably overlain by Early Devonian clastic rocks in the south (Ds of Reiser and others, 1980) and the Mississippian Kekiktuk Conglomerate.

There was at least one, and possibly two, pre-Mississippian deformational events. The first event was probably a compressional event during Early Devonian or Late Silurian time, as represented by the unconformity at the base of Ds. This compressional event collapsed the early Paleozoic basin/continental margin, telescoping the originally widely-spaced topographic features of the basin. The massive and structurally competent units (Nanook Limestone and Whale Mountain Volcanics) remained stratigraphically intact and relatively undeformed. Stratified sequences consisting of thick, competent units alternating with thin incompetent units (for example, 'qs' and 'bl') deformed via thrust faulting and related folding. The relatively incompetent, lithologically uniform and thin-bedded basin-fill deposits deformed homogeneously and pervasively.

Regional evidence and evidence from this study suggest that the deformation was north-vergent, but microscopic structures suggesting pre-Mississippian microscopic sinistral shear from areas to the west have been interpreted as evidence of south-vergent pre-Mississippian deformation (Oldow and others, 1987). It is not clear which unit of the pre-Mississippian sequence these structures were found in, or their relationship to either pre-Mississippian or Cenozoic map-scale structures. It therefore may be difficult to evaluate the true significance of this microscopic evidence of sinistral shear. No evidence of an early south-vergent deformational event was found in this study area. To the contrary, upright and steeply south-dipping beds beneath the unconformity in areas where there has been no Cenozoic slip along the unconformity surface and apparent northward older-over-younger relationships within the pre-Mississippian rocks suggest that this early deformation may have been north-vergent.

The pre-Mississippian rocks are unconformably overlain by a Middle Devonian clastic sequence ('Ds', Reiser and others, 1980) that may itself be slightly discordant with respect to the pre-Kekiktuk unconformity. This raises the possibility that there was a second, less severe deformational event prior to Kekiktuk deposition (W. K. Wallace, personal comm.). This event could have been either the waning phases of the earlier compressional event, or an extensional event.

These speculations provide a possible scenario for the pre-Mississippian evolution of the northeastern Brooks Range, but do not represent a unique solution. The observation that the pre-Mississippian stratigraphy of the northeastern Brooks Range is probably correlative with that of the Canadian Cordillera (Lane and Cecile, 1989), and possibly with the Franklinian Geosyncline of the Canadian Arctic Islands (Lerand, 1972), places some constraints on the amount Arctic Alaska could have been displaced during the opening of the Canada Basin. An extensive early Paleozoic carbonate platform/basin transition along the length of the Canadian Cordillera into Alaska does suggest that a continental margin existed in this area during early Paleozoic time. This data suggests that, in northeastern Alaska, this continental margin faced south <u>in present coordinates</u>, but does not constrain the facing direction of that margin prior to the opening of the Canada basin. Depending on the model used for the opening of the Canada basin, the pre-Mississippian rocks in northeastern Alaska could represent a south-facing continental margin (left-lateral strike-slip model) or a west-facing margin (rotational model). Further study of both the stratigraphy and structure of these rocks and similar age rocks in the circum-Arctic region is necessary in order to address this problem.

Acknowledgements

This project was supported by industry grants to the Tectonic and Sedimentation Research Group at the University of Alaska. Sponsors include ARCO, Chevron, Exxon, Murphy, Phillips, Shell, Standard and Texaco. Additional grants were received by the author from Amoco, the Geological Society of America and Sigma Xi. Special thanks are due to the U.S. Fish & Wildlife Service for providing helicopter time at cost. Wesley K. Wallace contributed insights into the regional structural relationships between the pre-Mississippian rocks and the younger Ellesmerian sequence. Larry Lane of the Geological Survey of Canada deserves special thanks for providing the Canadian perspective on these enigmatic pre-Mississippian rocks, both in and out of the field.

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UNIT DESCRIPTIONS

Qal	Quaternary alluvium

Mississippian through Cretaceous rocks

JKk	Jurassic and Cretaceous Kingak Shale. Black, fissile shales with occasional thin beds of siltstone and fine-grained sandstone. Total thickness undetermined.
Trkc	Triassic Karen Creek Sandstone. Dark gray-weathering, sooty gray, fine- to medium-grained quartz lithic phosphatic sandstone. Massive, highly bioturbated with few preserved sedimentary structures. Approximately 30 to 45 meters thick.
Trs	Triassic Shublik Formation. Black, thinly bedded, phosphatic shale, siltstone, fine-grained sandstones and minor black fossiliferous limestones. Locally highly deformed. Thickness cannot be determined in study area.
Trlf	Triassic Ledge Sandstone/Fire Creek Siltstone (Undifferentiated) members of the Ivishak Formation. Tan- to orangish tan-weathering, fine- to medium-grained pyritic quartz sandstone and siltstone, with local grit and pebble conglomerates. Massive with few sedimentary structures, except for local low-angle crossbedding. Bedding generally <.5 meters thick. Forms prominent ridges of frost-riven rubble. Approximately 65 to 90 meters thick.
Trks	Triassic Kavik Shale member of the Ivishak Formation. Brown, thinly bedded siltstone and shale. Poorly exposed in study area. Approximately 130 meters thick.
Pe	Permian Echooka Formation. Reddish-brown, thinly bedded (10 cm) calcareous bioclastic limestones, calcareous sandstones and bioturbated siltstones. Approximately 50-100 meters thick.
TrPs	Triassic and Permian Sadlerochit Group, undifferentiated. Siliciclastic sediments, including the Permian Echooka Formation, Triassic Kavik Shale, Triassic Ledge Sandstone,Triassic Shublik Formation, and Triassic Karen Creek Sandstone. Total thickness approximatedly 500 meters

Pw Pennsylvanian Wahoo Formation. Light gray- to buff-weathering skeletal and oolitic grainstones and bryozoan packstones. Contains prominent orange-weathering horizons toward top. Thickens from 200 meters in the west to approximately 300 meters in east.

Ma Mississippian Alapah Formation. Light gray-weathering peloidal packstones. Approximately 400 meters thick.

MPl Mississippian and Pennsylvanian Lisburne Group. Undifferentiated massive limestones of the Mississippian Alapah Formation and Pennsylvanian Wahoo Formation. Total thickness approximately 600 meters.

Mel Mississippian Endicott Group--limestones. Overlies Mes. In the north, thin-bedded skeletal grainstones with locally well-developed coral boundstones. Very fossiliferous, with abundant corals, brachiopods and crinoids. In the south, orange-weathering calcareous sandstones and sandy limestones. Gradational contact with overlying Alapah Limestone. Thickness laterally variable from < 50 meters to > 200 meters.

Mes Mississippian Endicott Group--siliciclastic sediments. Black, locally deformed shales and siltstones with minor thin-bedded (<30 cm), fine- to course-grained, quartz lithic sandstones. Approximate thickness of 200 meters, but this may include some structural thickening.

Meu Mississippian Endicott Group undifferentiated. Includes both the siliciclastic and calcareous sediments of the Endicott Group. Does not include Kekituk Conglomerate.

Mkk Mississippian Kekiktuk Conglomerate. White to light grey quartz and chert pebble and granule conglomerates and coarse sandstones. Thickness highly variable, ranging from 0 to 30 meters.

Pre-Mississippian rocks

bl Black massive bedded limestones. Locally pelloidal, but often recrystallized with extensive networks of filled fractures. Approximately 170 meters thick. Mapped as 'pCl' by Reiser and others (1980). True age unknown, possibly early Paleozoic.

rl Rippled-laminated sandy limestones and calcareous sandstones. Tan and orangish weathering, thin-bedded rippled calcareous clastic rocks with thin interbeds of black shale. Quartz is dominant detrital component. Local beds of massive recrystallized limestone. Often highly deformed, estimated thickness 180 meters. Mapped as 'pCls' and 'pClr' by Reiser and others (1980). True age unknown, possibly early Paleozoic.

ba Brown, black or tan argillites and shales. Contains thin beds of ripple-laminated, tan sandy limestones. Highly deformed, estimated thickness <200 meters. True age unknown, possibly early Paleozoic.

rss Red-weathering lithic sandstones. Fine-grained, probably volcaniclastic sandstones. Thickness indeterminate. Locally mapped as 'pCv' by Reiser and others (1980). True age unknown, possibly early Paleozoic.

vs Volcaniclastic sediments. Red-weathering, coarse- to fine-grained sandstones and local conglomerates. Thickness indeterminate. Locally mapped as 'pCv' by Reiser and others (1980). True age unknown, possibly early Paleozoic.

qs Quartz sandstones. Greenish-brown weathering, fine- to coarse-grained sandstones. Locally ripple-laminated. Interbeds of maroon and tan slates with occasional bioturbation on bedding surfaces. Estimated thickness of 275 meters, but may be more or less due to structural complications. Mapped in part as 'pCn' by Reiser and others (1980). True age unknown, possibly early Paleozoic.

ms Maroon slate. Red, maroon and tan slates interbedded with qs. Well-developed slaty cleavage. Generally thin (<1meter), locally >10 meters outcrop thickness.

qa Cherts with interbedded siltstones and shales. Cherts are thin-bedded (<30 cm) white- and pink-weathering with thin, maroon-weathering, ripple-laminated fine-grained sandstones and siltstones at tops of beds. Interbedded slaty shales are tan-weathering. Estimated thickness of <100 meters. Possibly early Paleozoic in age. Locally, possibly equivalent to 'pCpq' of Reiser and others (1980).

bs Brown-weathering shales and argillites. Contains local thin to moderately bedded (<30 cm) intervals of ripple-laminated calcareous limestones; and local maroon and green argillites with thin green cherts. Highly deformed, thickness indeterminate. Possibly equivalent to 'pCpa' and 'pCal' of Reiser and others (1980)

ch Cherts. Thin-bedded (10-15 cm), grey, black and white cherts. Estimated thickness <100 meters. Possibly equivalent to 'Ccp' of Reiser and others (1980). True age not documented, possibly early Paleozoic.

css Calcareous quartz sandstones. Thin- to moderately-bedded tan-weathering and fine-grained sandstones. Commonly ripple-laminated and interbedded with black shales. Thickness indeterminate due to structural thickening, probably greater than 200 meters. In map area, possibly equivalent to Css and pCn of Reiser and others (1980). True age not well-documented, probably early Paleozoic.

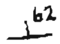
lss Lithic sandstones. Moderate- to thickly-bedded (>20 cm) grayish-black weathering fine- to medium-grained lithic sandstones. Interbedded with black shales. True thickness indeterminate due to probably structural thickening, but probably greater than 200 meters. Probably equivalent to 'Cs' as mapped by Reiser and others (1980). Considered early Cambrian in age, but true age not well-documented. Probably early Paleozoic in age.

ps Black phyllitic shales. Contains thin intervals of fine-grained, dark grey lithic sandstones and local pebbly mudstones. Highly deformed and structurally disrupted, and thickness indeterminate. Probably equivalent to 'Cp' by Reiser and others (1980). Early Cambrian age not well-documented, but probably early Paleozoic in age.

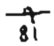
pMu Pre-Mississippian sediments, undifferentiated.

GEOLOGIC MAP SYMBOLS

Strike and dip of beds



Strike and dip of beds in pre-Mississippian rocks were tops can be determined.

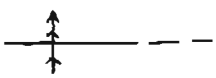


Strike and dip of overturned beds


Strike and dip of beds where visually estimated

Strike and dip of foliation or cleavage


Trend and plunge of trace of fold axis, dashed where approximately located.

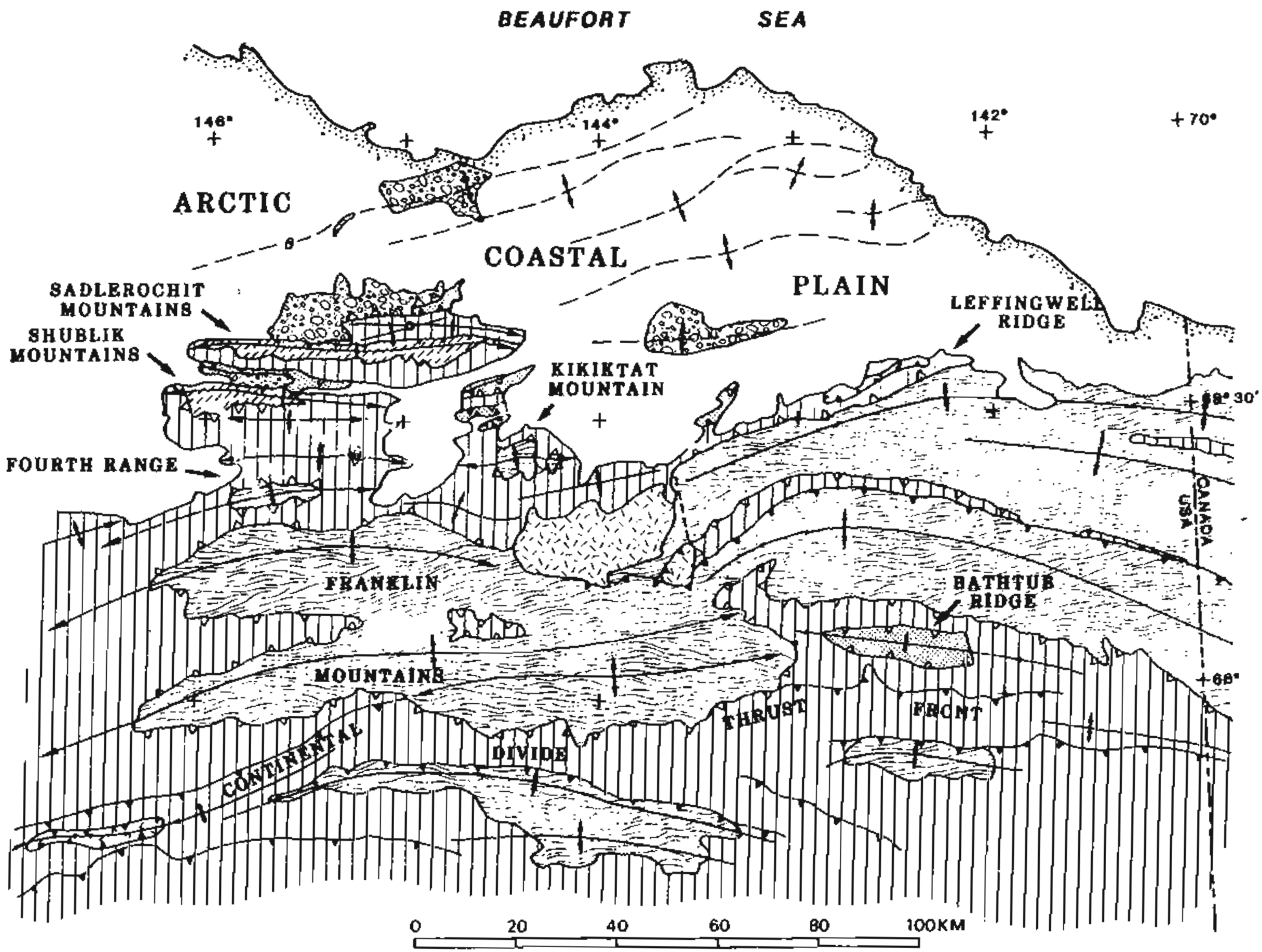

Trend of axial surface of flexure where dip changes magnitude but not direction.

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.

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

TECTONIC MAP OF THE NORTHEASTERN BROOKS RANGE



FROM:

WALLACE AND HANKS, 1988

W.K.WALLACE OCTOBER,1987
MODIFIED FROM BADER & BIRD,1986
& U.S. DEPT.OF INTERIOR,1987

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

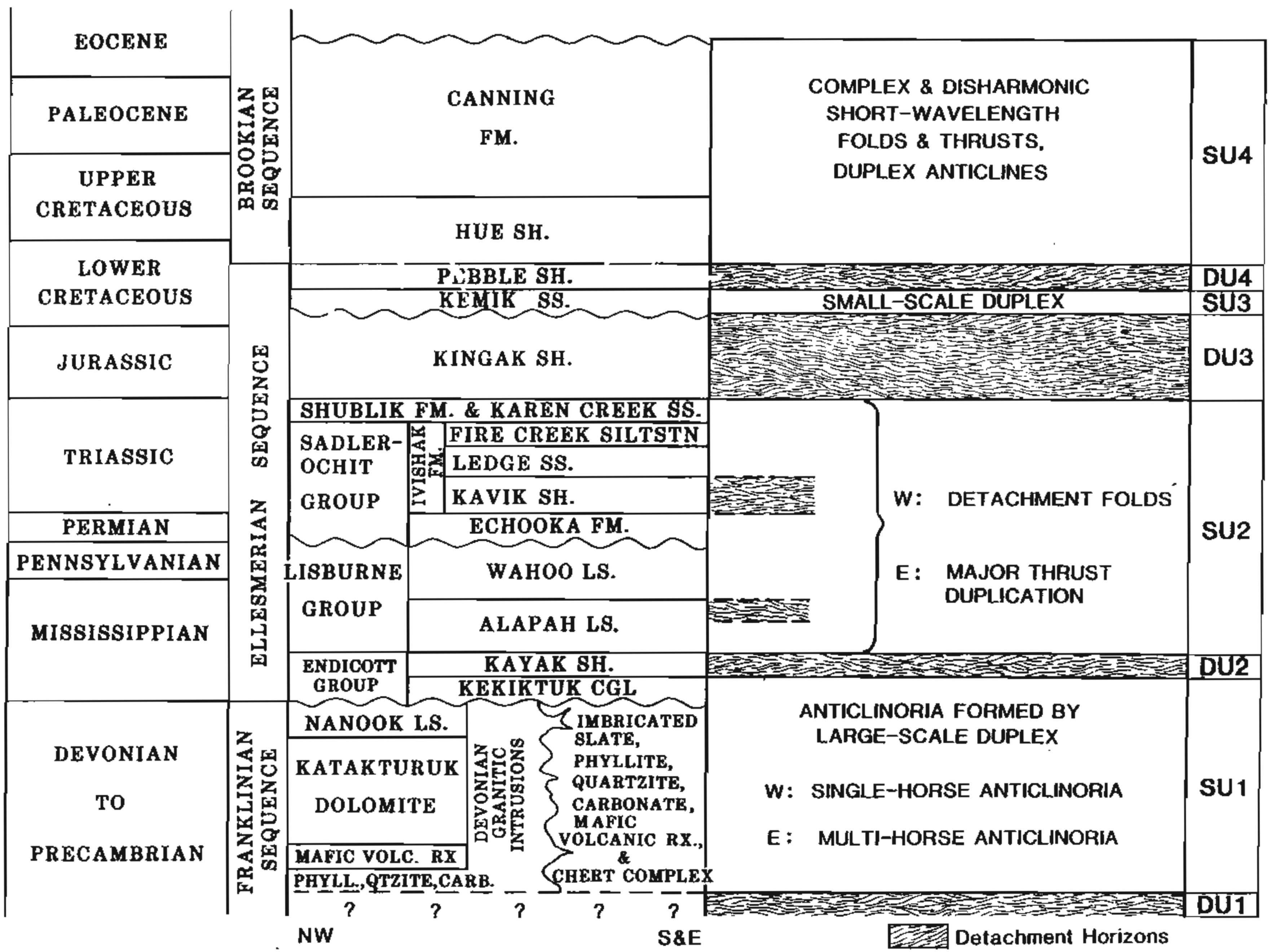

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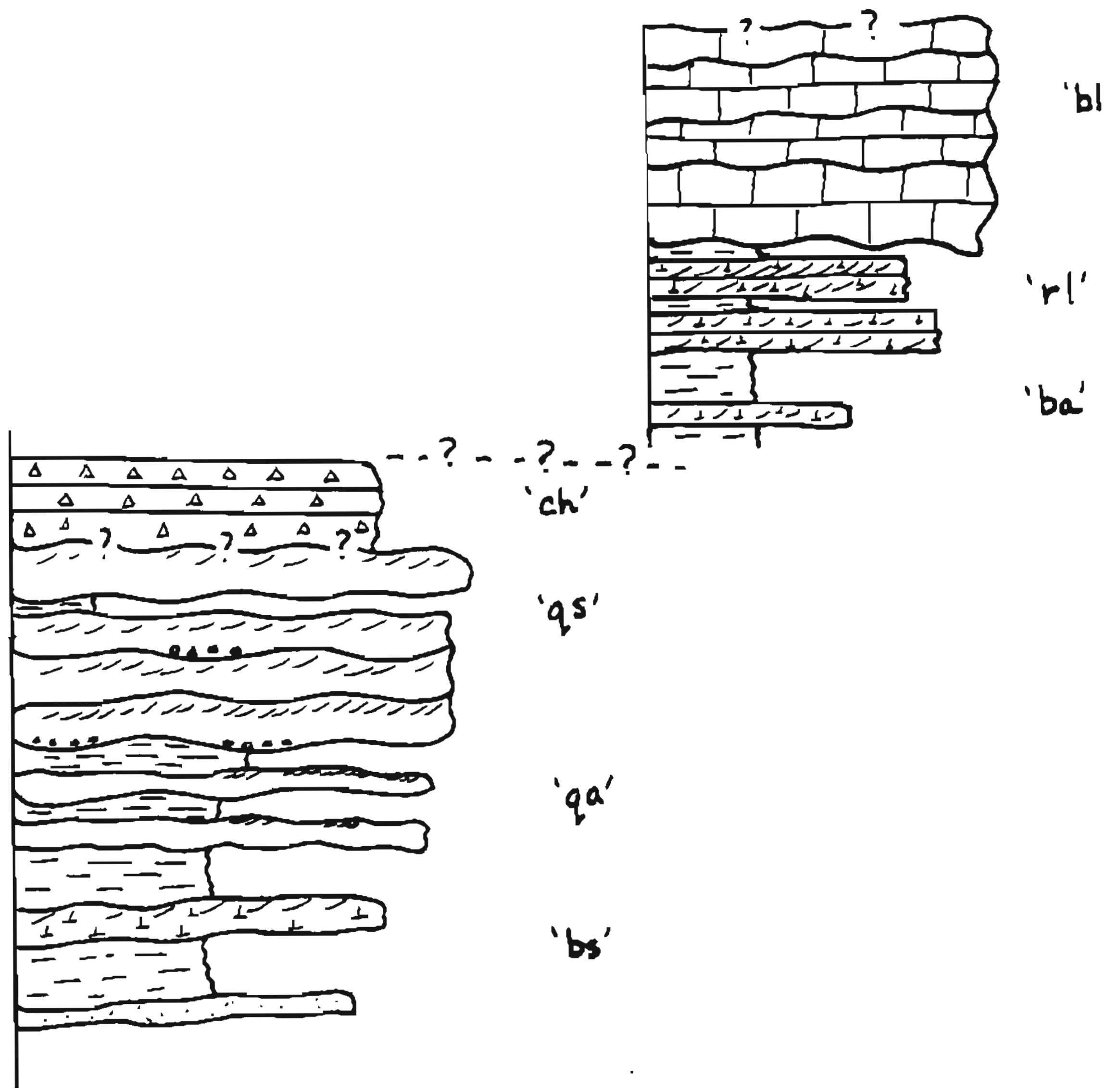
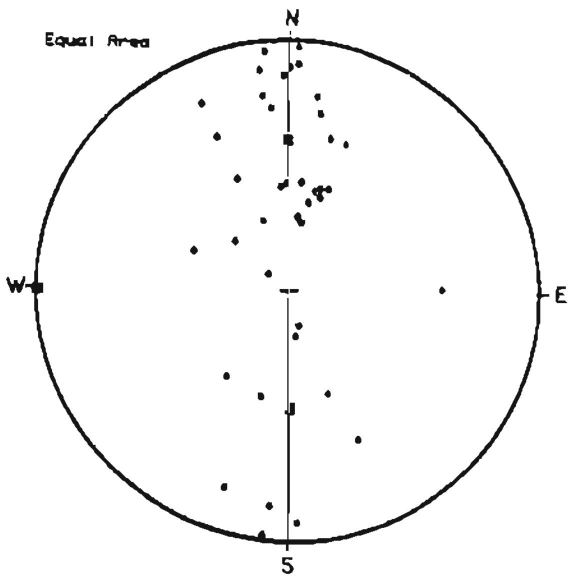
FIGURE 2.

FIGURE 3. Stratigraphy of the pre-Mississippian rocks of the Aichilik and Egaksrak River area.



A.



B.

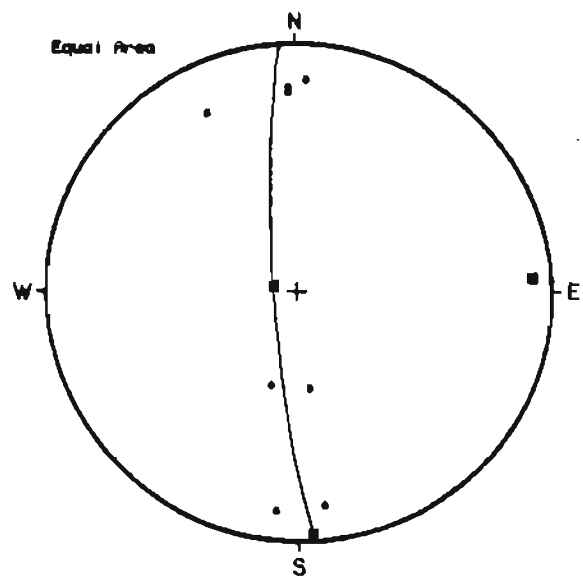
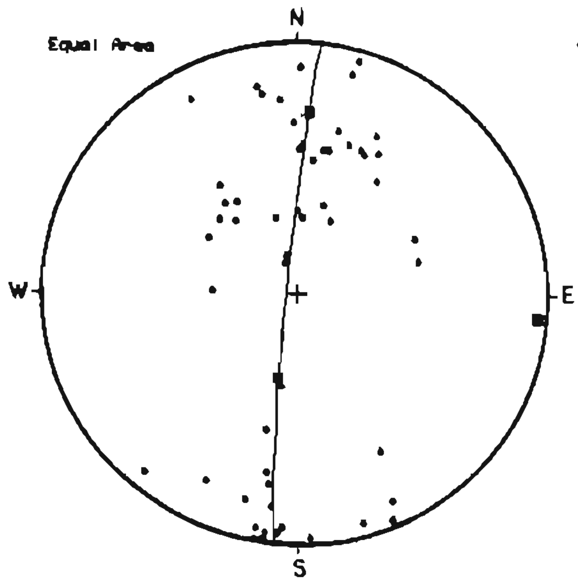


Figure 4.

A. Bl, ba and rl, poles to bedding
N = 41

B. Bl, ba and rl, poles to S1
N = 8

A.



B.

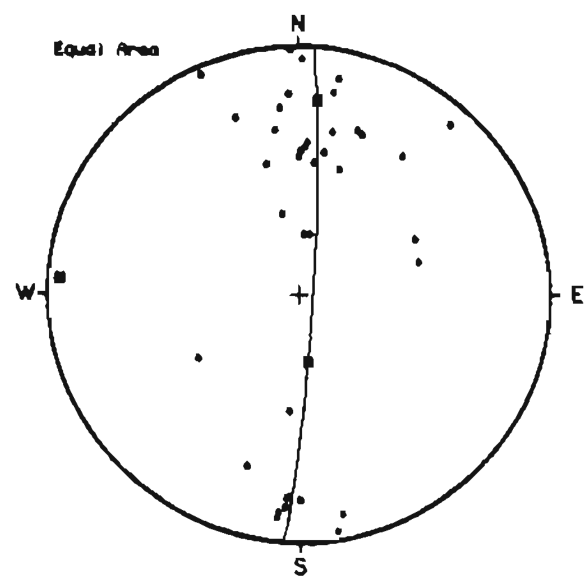
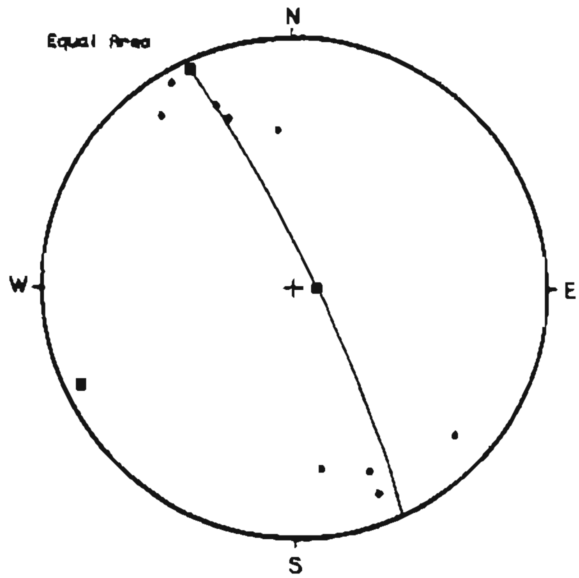


Figure 5.

A. Qs, qa and bs, poles to bedding.
N = 56

B. Qs, qa and bs, poles to S1.
N = 38

A.



B.

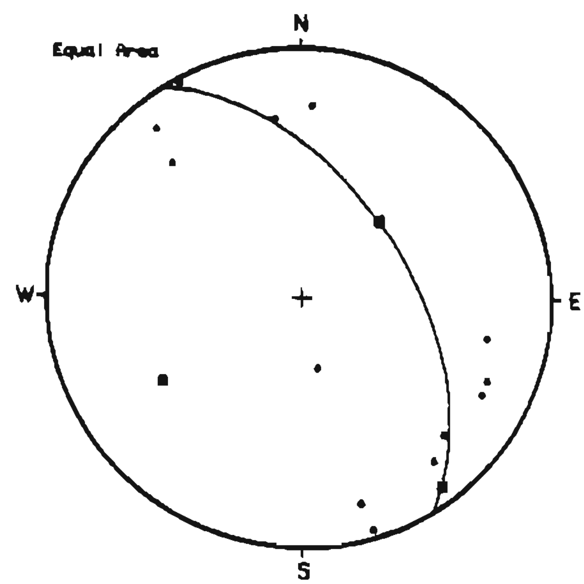


Figure 6.

A. Bl, rl and ba, poles to S2
N = 9

B. Qa and bs, poles to S2
N = 13

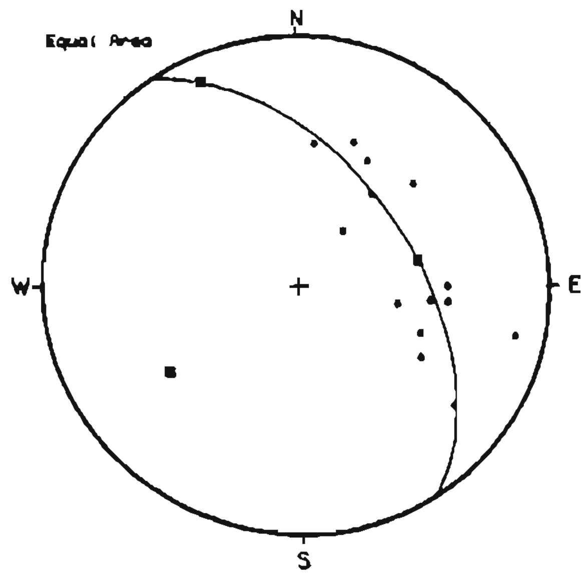


Figure 7.

RJ in footwall of Cenozoic thrust
Poles to bedding
N = 14

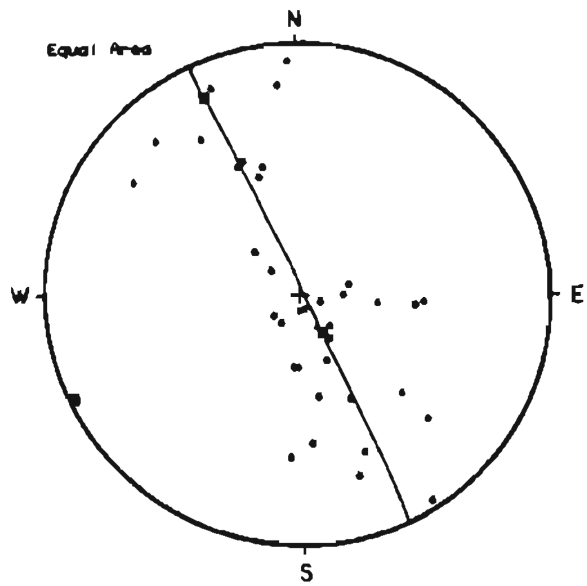
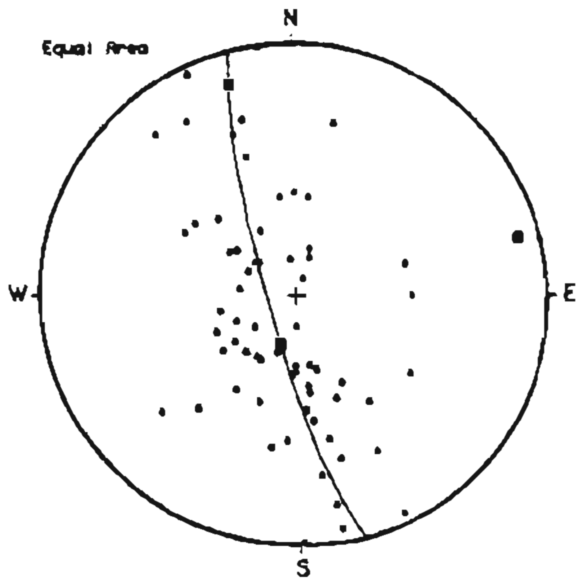


Figure 8.

Mississippian Kayak Shale and Kayak limestone (Mes and Mel) in footwall of Cenozoic thrust

Poles to bedding
N = 38

A.



B.

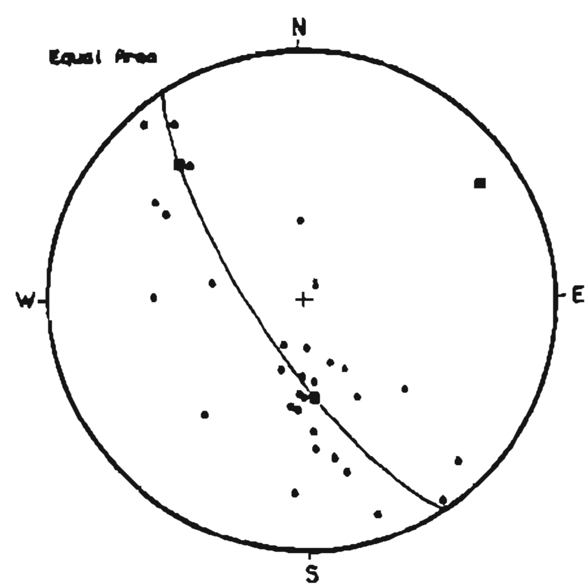


Figure 9.

A. MPl and TrPs of Leffingwell Ridge, poles to bedding.
N = 65

B. MPl and TrPs of Egaksrak River klippe, poles to bedding.
N = 32

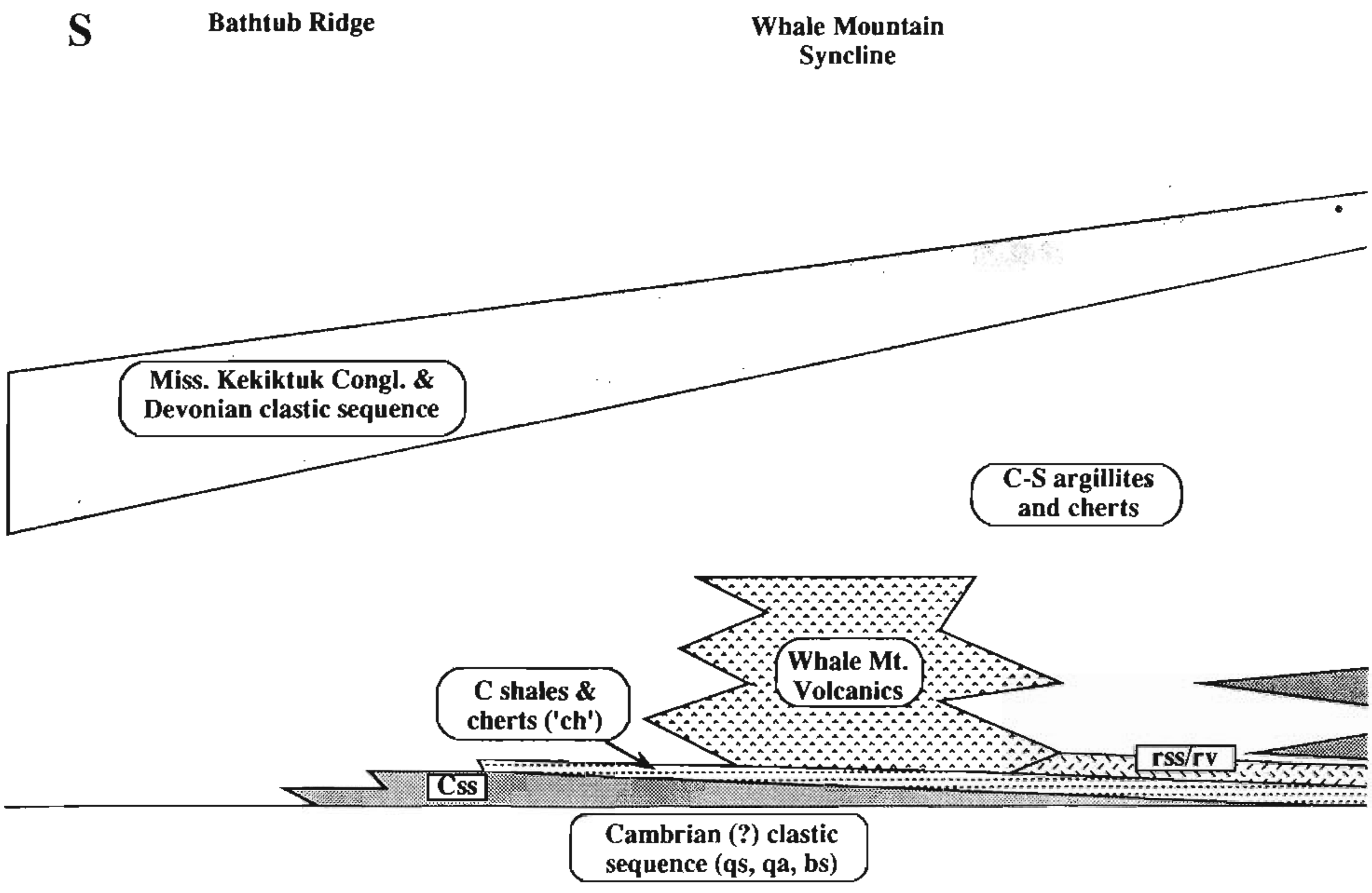
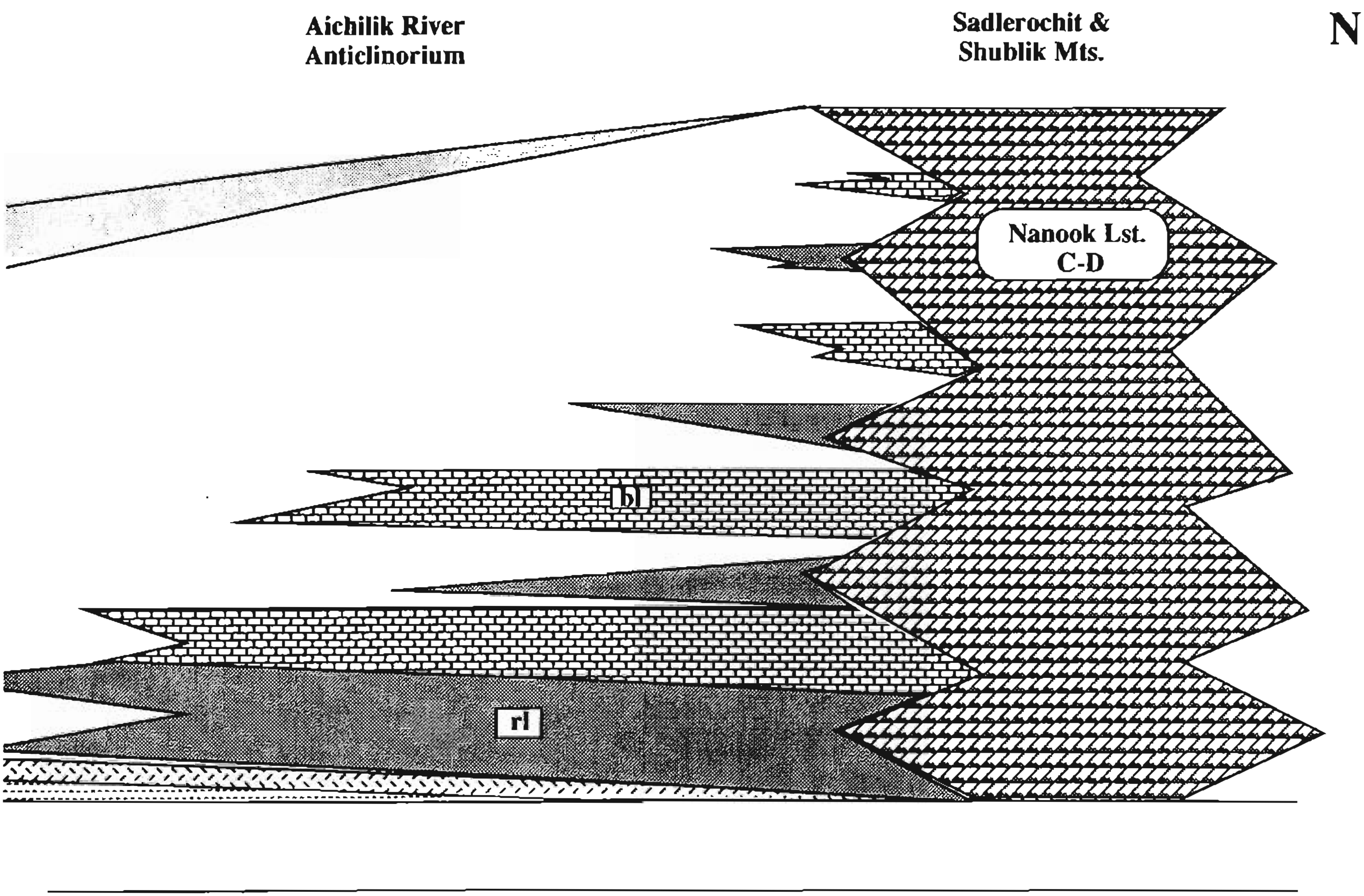


Figure 10. A speculative early Paleozoic regional stratigraphy of the northeastern Brooks Range


Aichilik River
Anticlinorium
Sadlerochit &
Shublik Mts.
N
Nanook Lst.
C-D
bl
rl