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PRELIMINARY OBSERVATIONS OF THE STRAIGHT CREEK DETACHMENT ANTICLINE, NORTHEASTERN BROOKS RANGE, ALASKA: A BASIS FOR GEOMETRIC AND KINEMATIC MODELS FOR DETACHMENT FOLDS

by

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ABSTRACT

Detachment folds are very common structures in fold-and-thrust belts but currently are poorly understood and hence are not reconstructed using an established, consistent method. This report presents observations of the characteristics of the Straight Creek detachment anticline (SCDA), as an early phase in a general study about the geometry and kinematics of detachment folds. Ultimately, this study aims to establish quantitative geometric and kinematic models that can be used to better recognize and consistently reconstruct the geometry of detachment folds in fold-and-thrust belts. The Straight Creek detachment anticline (SCDA) is the first fold to be analyzed in the general study. Observations from the SCDA will be incorporated with observations from other detachment folds in order to guide the construction of the new more actualistic geometric and kinematic models.

The SCDA is an open inclined fold at the headwaters of Straight Creek in Alaska's northeastern Brooks Range. The fold is defined by competent carbonate rocks of the Carboniferous Lisburne Limestone. The shortening required to form the fold occurred above a detachment in the Mississippian Kayak Shale and is accommodated in the Kayak Shale by internal deformation. The Kayak Shale is 1.5 times thicker in the anticlinal core than it is beneath the limbs of the SCDA. The detachment is underlain by, in descending order, the Mississippian Kekiktuk Conglomerate, a regional angular unconformity, and poly-deformed pre-Mississippian rocks.

Regionally, the SCDA is above the roof thrust of a forward (north)-propagating, hindward-dipping passive-roof duplex with horses defining fault-bend folds (Wallace, 1992). The SCDA lies above the north-dipping forelimb of one of these fault-bend folds and it records a south-directed or backthrust sense of displacement relative to the underlying forelimb.

The geometry of the SCDA and distribution of outcrop-scale structures within the fold suggest a complex kinematic evolution. Geologic indicators of irreversible strain are present in two of the three hinges of the SCDA, area-loss in the core of the fold is suggested by a well-developed solution cleavage in the Kayak Shale, and no apparent structural overprinting indicative of hinge migration is observed on the limbs of the fold. These and other observations, including quantitative strain data, will be used to develop a realistic geometric and kinematic model for the SCDA to be modified from a model by Homza and Wallace (in review). This model will be a modification of the current model of Homza and Wallace (in review). In the last stage of the larger study, data from several other detachment folds will be incorporated into a general best-fit model for detachment folds.

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INTRODUCTION

This report presents preliminary findings of the 1992 field studies conducted at the Straight Creek detachment anticline (SCDA) in the northeastern Brooks Range of Alaska. The SCDA is being analyzed as part of a general, multi-faceted study of the geometric and kinematic properties of detachment folds. The purpose of this report is to describe the geometry and internal deformational features of the SCDA and to discuss its significance in the context of the general study.

The SCDA is an excellent example of a detachment fold. A detachment fold is defined as "a fold in a relatively competent rock unit that is accommodated by internal deformation of a less competent unit that is, in turn, separated by a surface or zone of displacement (detachment horizon or décollement) from another competent unit that bounds the fold" (Homza and Wallace, in review) (Fig.1). Detachment folds are probably very common in fold-and-thrust belts worldwide but commonly are not recognized as detachment folds and thus are currently poorly understood (Homza and Wallace, in review).

In the general study, the geometry and strain distribution of detachment folds in the northeastern Brooks Range are being analyzed in order to develop a consistent and quantitative means of describing and reconstructing their evolution. This work aims ultimately to provide one or more actualistic geometric and kinematic models for detachment folds that will be comparable to existing models for two other common types of fault-related folds: fault-bend folds (Suppe, 1983) and fault-propagation folds (Suppe and Medwedeff, 1990; Mitra, 1990) (Fig. 2). These models have been used successfully in analyzing fault-bend and fault-propagation folds, which, together with detachment folds, represent common structural hydrocarbon trap types. However, no comparable detailed models currently exist for detachment folds. Thus, unlike the other two fold types, there is neither a widely used standard for identifying detachment folds nor a model that allows consistent and quantitative reconstructions of detachment folds. The current study seeks to develop such a model (or models) using the well-exposed detachment folds in the northeastern Brooks Range (e.g. the SCDA) as the primary guide in an iterative process of geometric/kinematic modeling. The main objectives of the general study are to provide:

1) a better basis for the recognition of natural detachment folds and a better understanding of their evolution.

2) a more general and applicable basis for consistent and quantitative reconstructions of natural detachment folds than is provided by existing models.

3) a model that can easily be modified to fit observed detachment fold geometries and the character and distribution of internal structures and strain within those folds.

The SCDA is the first fold in the general study to be analyzed in detail. The starting point for the forthcoming modeling process is the current idealized model for detachment folds of Homza and Wallace (in review), which provides general constraints on the geometry and kinematic evolution of detachment folds. That model is very idealized because it is based on untested assumptions. The explicit assumptions of that model will be systematically tested and modified in this study, guided by the observations of natural folds, in order to produce more actualistic models. Our idealized model for detachment folds (Homza and Wallace, in review) assumes:

- Parallel folding of the competent unit (constant bed-length and thickness)
- A triangular fold form
- Constant cross-sectional area
- Constant detachment depth
- No overlap of adjacent detachment folds
- No bed-parallel shear outside of detachment anticlines
- Evolution of detachment folds by hinge migration (a consequence of some of the assumptions above)

The SCDA will be used as a guide in the process of modifying these assumptions in order to produce a "first-order" geometric and kinematic model for detachment folds. Other folds will be analyzed and all of the data will be combined in order to produce higher-order best-fit models that are designed to provide a basis for the quantitative assessment of detachment folds.

The main objectives of the Straight Creek portion of the general study are to:

1) describe, in detail, the structural geometry of the SCDA.
2) assess the distribution and relative age of internal structures and strain within the SCDA.
3) develop a balanced cross section across the SCDA, incorporating geometric and strain data, to be used as a guide in developing more refined geometric and kinematic models for detachment folds.
4) identify and mathematically evaluate the natural factors that require modification of the explicit assumptions of our current model.

This project will ultimately yield a very useful tool for both understanding the evolution of external regions of mountain belts in general, and for assessing the potential of particular hydrocarbon traps. This preliminary report describes only the geometric aspects of the SCDA while the strain analyses needed for a complete kinematic description are being conducted. Since this is only a preliminary description of the first fold analyzed in the current study, no modifications to our current model are offered herein.

LOCATION AND GEOLOGIC SETTING

The SCDA is located at the headwaters of the north-flowing Straight Creek, along the eastern boundary of that watershed in the Mt. Michelson B-3 Quadrangle, Townships 2S and 1S, Ranges 27E and 28E of northeastern Alaska (Fig. 3). The study area covers approximately 25 km^2 in the northern Franklin Mountains of the northeastern Brooks Range (Figs. 3 and 4).

Regional stratigraphy

The rocks of the northeastern Brooks Range are divided into three sequences. In ascending stratigraphic order, these are the poly-deformed "pre-Mississippian rocks" (low-grade metasedimentary and metavolcanic basement), the Mississippian-Neocomian Ellesmerian passive continental margin sequence, and the Hauterivian-present foredeep deposits of the Brookian sequence (Fig. 5). A regional sub-Middle Devonian angular unconformity separates the pre-Mississippian rocks from the Ellesmerian sequence everywhere in the northeastern Brooks Range.

Tectonic setting

The Brooks Range is a more than 100-km wide, east-west trending orogenic belt in northern Alaska that extends from the Yukon Territory in the east to the Chukchi Sea in the west (Moore and others, in press) (Fig. 3). The northeastern Brooks Range fold-and-thrust belt extends north of the main axis of the Brooks Range, east of the Sagavanirktok River, as a northward convex arcuate topographic salient. The study area is part of the "western structural province" of the northeastern Brooks Range, as defined by Wallace and Hanks (1990).

The outcrop pattern in the western structural province defines a series of arcuate (northward convex) east-west trending belts alternating between pre-Mississippian rocks and Ellesmerian sequence rocks. The pre-Mississippian rocks are exposed in anticlinoria that represent horses in a regional forward (northward)-propagating duplex that extends from at least the continental divide area in the south, north to the Arctic coastal plain (Figs. 3 and 6) (Namson and Wallace, 1986; Wallace and Hanks, 1990). The geometry of the duplex suggests that these anticlinoria are fault-bend folded horses formed between a floor thrust in the pre-Mississippian rocks and a roof thrust in the Mississippian Kayak Shale (Namson and Wallace, 1986; Wallace and Hanks, 1990). The duplex has been described by Wallace (1992) as a "passive roof duplex", a duplex in which displacement on the roof thrust is in a hindward direction (Banks and Warburton, 1986).

Shortening above the roof thrust in the Kayak Shale has been accommodated primarily by kilometer-scale detachment folds with a distinct lack of thrust faults (Wallace and Hanks, 1990; Wallace, 1992). The detachment folds are defined by the competent carbonates of the Mississippian-Pennsylvanian Lisburne Group while the Kayak Shale serves as the detachment horizon. A south-directed, or back-thrust, sense of displacement (with respect to the underlying duplex) is accommodated by these detachment folds (Wallace, 1992). The SCDA represents a well-exposed example of one of these detachment folds and it is thought to be located structurally above the hangingwall ramp of the "northern Franklin Mountains horse" of the regional duplex. This is the second major horse north of the currently recognized southern limit of the duplex (Wallace, 1992).

PREVIOUS REGIONAL WORK

Significant summary studies

Moore and others (in press) present an overview of the geologic history of the northeastern Brooks Range. An overview of, and model for, the structure of the northeastern Brooks Range is presented by Wallace and Hanks (1990), and an alternative model by Oldow and others (1987). Regional geologic maps include Bader and Bird (1986) and Reiser (1980).

Local geologic work

A sedimentologic study of the Mississippian Endicott Group was carried out near the headwaters of Straight Creek by Lepain and Crowder (1989). Structural studies, focusing on the nature of the sub-Mississippian rocks and sub-Mississippian unconformity (SMU) were conducted by Oldow and others (1987) with the aim of addressing more regional tectonic issues. Wallace (1992) described the structure along a north-south transect across the northeastern Brooks Range, including the study area, and defined the geometry of a passive roof duplex overlain by detachment folds.

DETACHMENT FOLDS

Alternating mechanically competent and incompetent rock units constitute the stratigraphy in most fold-and-thrust belts, and folds in relatively competent units with thickened internally deformed weaker rock in their cores - detachment folds - are very common structural features. The SCDA is an excellent example of a detachment fold with all of the defining features exposed (compare figs. 1 and 7), including the competent unit (the Lisburne Limestone), the incompetent unit (the Kayak Shale), the detachment zone (near the base of the Kayak Shale), and the bounding competent unit (the Mississippian Kekiktuk Conglomerate together with the pre-Mississippian rocks).

Previous studies of detachment folds

Structural geometries characteristic of detachment folds have been recognized since the 19th century (see Willis and Willis, 1934 for a review). Dahlstrom (1969, 1990) described the fundamental geometric characteristics of detachment folds and qualitatively suggested inherent kinematic constraints upon them. Homza and Wallace (in review) have developed a succinct definition for detachment folds, as given above.

Using the conservation of bed-length and area, Jamison (1987) and Mitra and Namson (1989) presented trigonometric analyses of detachment folds. Although these were important conceptual studies, these models address a relatively restricted range of detachment fold geometries and they do not consider the full range of variables that influence the geometry and kinematic behavior of detachment folds. Homza and Wallace (in review) also used the conservation of bed-length and area in developing a very idealized geometric model for detachment folds that allows calculation of either shortening or detachment depth using fold geometry and requires hinge-migration kinematics. This model provides the conceptual basis for the present study.

Significance of detachment folds

Detachment folds are one of three currently recognized thrust-related folds observed in fold-and-thrust belts (Jamison, 1987) (Fig. 2). The other two types are fault-bend folds (Suppe, 1983) and fault-propagation folds (Suppe and Medwedeff, 1990; Mitra, 1990). Detachment folds differ from the other two types in that detachment folds do not initially involve thrust ramps in their cores, but rather involve structurally thickened incompetent rock in that position. Detachment folds may be truncated by thrust faults after their formation making them difficult to distinguish from fault-propagation folds (Homza, 1992a).

The importance of distinguishing among these three thrust-related fold types stems from the fact that they each evolve along significantly different kinematic paths resulting in different geometries. In order to predict subsurface geometries accurately, the petroleum geologist must correctly identify the fold-type and apply a quantitative model to constrain the possible geometric solutions for the target. Also, balancing structural cross sections to understand the evolution of the external regions of mountain belts requires the correct choice of fold-type and model. Thus, from both an applied and purely scientific standpoint, the nature of detachment folds is of significance.

The kinematics of detachment folds - hinge migration or fixed arc-length folding?

Empirical observations and mechanical considerations suggest that buckle folds in a competent layer bounded by incompetent material nucleate with an arc-length that is a function of rheology and competent layer thickness, and retain a constant arc-length (and hence, fixed hinges) as shortening increases and the fold grows (de Sitter, 1956;

Biot, 1961; Currie and others, 1962; Ramberg, 1964; Ramsay, 1967, 1974; Johnson, 1977; Abassi and Mancktelow, 1992; Fischer and others, 1992; Mancktelow and Abassi, 1992) (Fig. 14a). Mitchell and Woodward (1988) assumed that detachment folds form by this fixed arc-length buckling mechanism, and Fischer and others (1992) provide evidence for fixed-hinge growth of several natural folds that could be interpreted as detachment folds.

Dahlstrom (1990) pointed out that fixed arc-length folding is incompatible with the fundamental concept of conservation of cross-sectional area, which implies a linear relationship between shortening and cross-sectional area uplifted above base level (e.g. Fig. 15). In contrast, Wiltschko and Chapple (1977) documented a non-linear relationship between uplifted area and shortening for symmetrical fixed arc-length folds (Fig. 16). The apparent contradiction is particularly obvious for folds with interlimb angles less than about 60^{o}, for which there is an inverse non-linear relationship between uplifted area and shortening (Wiltschko and Chapple, 1977). These relationships suggest that a fixed arc-length fold cannot evolve with a fixed detachment depth and still obey the law of conservation of cross-sectional area. Wiltschko and Chapple (1977) resolved this apparent contradiction by assuming that incompetent material moves from synclines to anticlines as uplifted area initially increases, then flows out of the anticlines as area decreases with increasing shortening. In this case, the detachment depth is not fixed.

In order for a detachment fold to grow with a fixed detachment depth, the uplifted area in its core must increase linearly as shortening increases. This requires an increase in the length of at least one fold limb, which in turn requires hinge migration (Fig. 14b). Growth of folds by hinge migration has been documented for kink bands (Weiss, 1968; Stewart and Alvarez, 1991), and has been used to model fault-bend folds (Suppe, 1983) and fault-propagation folds (Suppe and Medwedeff, 1990). Dahlstrom (1990) concluded that growth of detachment folds by hinge migration is likely, and the geometric models of Jamison (1987) and Mitra and Namson (1989) both assume a fixed detachment depth and fold growth by hinge migration. Hinge-migration kinematics are not an initial assumption of the current idealized model of Homza and Wallace (in review), hinge migration is a required consequence of the model.

Thus, a very fundamental question remains unanswered: What geometric and kinematic paths do detachment folds follow? The present study aims to address this question by evaluating natural fold geometries and kinematic indicators and to produce a better kinematic model for detachment folds based on the natural constraints. Some of the preliminary observations of the SCDA that bear on fold kinematics are noted below.

METHODS

This general study of detachment folds uses several distinct but related techniques. Geologic mapping (scale:1:25,000) is the essential data base, since it provides the basis for creating balanced cross sections which, in turn, establish a first-order approximation of the fold geometry. The cross section of the SCDA (Fig. 7) represents such a first-order approximation. This geometry will be refined on the basis of detailed strain analyses carried out on a variety of strain indicators using the Rf-ϕ method (Ramsay and Huber, 1983, 1987). The modeling process involves use of trigonometry to relate fold geometry and conservation of mass. A series of iterations will be done in which observations will guide changes in assumptions of Homza and Wallace (in review). Such changes limit the viable geometries and a best-fit match between natural folds and the model will be derived. The AutoCAD graphics package is used in constructing both the balanced cross sections and the geometric and kinematic models (Homza, 1992b).

GEOMETRY AND INTERNAL STRUCTURES OF THE STRAIGHT CREEK DETACHMENT ANTICLINE

The SCDA is an open, inclined, angular anticline that plunges 15 degrees to N87E. Competent carbonates of the Lisburne Group define the fold with a wavelength of about 840m, and the incompetent shales of the Kayak Shale are about 1.5 times thicker in the core than beneath the limbs of the SCDA (Fig. 7). Figure 7 is a balanced cross-section of the SCDA that is considered preliminary since it does not yet include strain data. The fold sits structurally above a relatively planar, north-dipping detachment surface near the base of the Kayak Shale that separates it from an underlying structurally competent package of rock. This lower structural package includes the Kekiktuk Conglomerate, the sub-Mississippian unconformity, and the pre-Mississippian rocks. Figure 8 displays the stratigraphy of the SCDA.

Although its axial surface dips about 58°S, the SCDA is relatively symmetrical and its axial surface is near-perpendicular to the underlying detachment surface. Its north limb (forelimb) is steep to overturned and its backlimb dips gently northward. A more complete numerical description of the fold is provided on figure 7. Observations of outcrop-scale structures are discussed below. Microscopic features have not yet been analyzed and, as a result, the amount of layer-parallel shortening and the distribution and significance of strain and incompetent flow are currently undetermined.

Internal structures of the Lisburne Limestone

The overall structural character of the Lisburne Limestone is dependent on both its internal stratigraphy and its structural position within the SCDA. A much greater frequency and degree of strain is observed near the hinge of the fold than is seen on the limbs and flexural-slip folding is indicated by limb structures. A N-S striking, essentially vertical joint set is everywhere in the Lisburne Group at Straight Creek.

The Lisburne Limestone in this area is divided into informal "lower" and "upper" structural units that are separated by a zone of weakness controlled by a competency contrast that displays structures indicating primarily bed-parallel displacement (minor shear zones, slickenfibers). The 60m thick lower Lisburne is composed of red-stained wackestone and packstone beds that are up to 1 meter thick whereas the 700m-thick upper Lisburne is characterized by 1m-5m thick beds of gray and tan mudstone to grainstone. The nature of folds that are parasitic to the SCDA defines the primary structural difference between the upper and lower Lisburne Group. The thinner beds of the lower Lisburne are commonly tightly folded (interlimb angles commonly less than 60^0), especially near the hinge of the SCDA, their axial surfaces are inclined toward the core of the larger fold. The thicker upper Lisburne beds display fewer folds that are gentle (interlimb angles about 130^0) with axial surfaces also inclined toward the core of the fold with no obvious sense of vergence.

Limb structures

Outcrop-scale internal deformational features within the Lisburne Group on the limbs of the SCDA include parasitic folds (with wavelengths of meters in the lower Lisburne and 10's of meters in the upper Lisburne), en echelon tension fractures, slickenfibers on interbed fault zones, minor thrust faults, and stylolites. The distribution and orientation of these features suggest flexural-slip folding: a north-over-south sense shear on the north limb (forelimb) and a south-over-north sense of shear on the southern limb (Fig. 9).

Hinge structures

The Lisburne Limestone in the hinge area of the SCDA is highly strained. As a result, the upper Lisburne has been eroded, leaving only the lower Lisburne exposed. Tight, overturned folds with calcite-filled saddle reefs (Ramsay, 1974), penetrative slatey cleavage, and minor south-over-north thrust faults are densely distributed in the hinge zone (Fig. 9). In outcrop, the pervasive cleavage obliterates macrofossils and all but the most distinct bedding surfaces; microscopic observations are pending. It is important to note that the structures distinguishing the hinge and limb areas were nowhere observed to overprint each other.

Internal structures of the Kayak Shale

Like the Lisburne Limestone, the structural character of the Kayak Shale is dependent on both its internal stratigraphy and its structural position within the SCDA. The variation in structural character as a function of structural position is particularly evident in the Kayak where two mechanically competent siliceous units approximately 10m thick are present between thicker incompetent units of shale that contain many meter-thick competent sand horizons (Lepain and Crowder, 1989). These different lithologies/competencies record different deformational features with the most important being the spectacularly folded competent units (Fig. 10). These folds are disharmonic with respect to the SCDA and are an order of magnitude smaller. The same N-S striking, steeply dipping joint set present in the Lisburne Limestone is evident in the Kayak Shale, especially in the competent units.

Limb structures

Structures within the Kayak Shale beneath the limbs of the SCDA include parasitic folds, minor thrust faults, "ductile" shear zones in shale units, and minor stylolites. Shear indicators, especially small scale folds in meter-thick sand horizons, show a south-over-north sense of shear on the backlimb of the SCDA and a north-over-south sense of shear on the forelimb.

Hinge structures

The hinge zone of the SCDA in the Kayak Shale is dominated by intense penetrative solution cleavage in shale units and tight folds in competent sand units (up to 10m in wavelength). Although centimeter-scale parasitic isoclinal folds are recognizable in shale horizons beneath the limbs of these folds, bedding in the shale horizons that occupy fold cores is transposed and nearly obliterated by the cleavage (Fig. 11). Shale units have been nearly completely squeezed out of the cores of these folds (Fig. 12). The folded thicker competent units show randomly distributed, closely spaced, quartz-filled fractures and minor thrust faults in the hinge zones (Fig. 12). These folds in the SCDA hinge zone show no dominant sense of vergence.

The bounding synclines of the Straight Creek detachment anticline

Establishing the geometry of adjacent folds in both the competent and incompetent units is critical in the analysis of any one detachment fold because this geometry influences the modeling process. In other words, the geometry and kinematics of adjacent folds are intimately related to that of the fold under consideration.

The syncline adjacent to the forelimb of the SCDA - the "forelimb syncline" - is a multi-panel, gentle, upright (with respect to the detachment) fold. The most significant hinge of this fold, in terms of modeling, is the southernmost hinge because this is the closest hinge to the SCDA and it is the hinge that marks the transition in the thickness in the Kayak Shale: south of this hinge, the Kayak drastically thickens toward the anticlinal core of the SCDA. Poor exposures north of the southernmost hinge of the forelimb syncline limit accurate estimations of the thickness of the Kayak Shale in this area. However, north-over-south shear indicators in the Kayak in the vicinity of the southernmost hinge of the forelimb syncline are present. In the Lisburne Limestone, the southernmost hinge zone is composed of angular parasitic folds rather than a single hinge. The hinge zones of each of these folds display structures indicative of irreversible strain such as penetrative cleavage, minor faults, and abundant veins.

The "backlimb syncline" of the SCDA is fully exposed at Straight Creek. It is a gentle and upright (with respect to the detachment) fold (Fig. 7). The Lisburne Limestone is folded in the hinge area into several open folds that display only minor penetrative fabrics, and south-over-north shear indicators in the Kayak Shale beneath this fold suggest thinning beneath the hinge. This thinning is not directly observed, but instead, the thickness of the Kayak beneath the panel south of the hinge of the backlimb syncline is approximately equal to (or even less than) that beneath the hinge. Thus, the observed geometry shows a gradational increase in the thickness of the Kayak from south of the backlimb syncline north to the anticlinal core.

Structural significance of the Kekiktuk Conglomerate, the detachment, and the sub-Mississippian unconformity

A form surface defined by the top of the Kekiktuk Conglomerate traces a north-dipping panel (27^{o}) in the area and is thought to reflect the geometry of the forelimb of the underlying northern Franklin Mountains horse (Namson and Wallace, 1986; Wallace, 1992). The upper part of the Kekiktuk displays several tight, north-vergent folds (Fig. 13), but Their bases are not exposed. These folds may have formed above a detachment within the Kekiktuk or they could reflect deformation in the pre-Mississippian rocks. Overall, the Kekiktuk appears to accommodate much less shortening than the overlying Kayak and Lisburne. Only local indications of significant internal penetrative strain (crenulation cleavage, quartz veining) are apparent within the Kekiktuk and are associated exclusively with the tight folds.

Shortening in the Kekiktuk is about 43% that of the Kayak (Fig. 7). This change in the amount of shortening occurs over a narrow stratigraphic zone. This situation requires detachment between the Kayak and the Kekiktuk and that the detachment horizon exist in this narrow zone near the bottom of the Kayak Shale or directly along the stratigraphic contact.

The erosional sub-Mississippian unconformity is exposed in several places in the study area. There is no observed indication of shear along the unconformity, nor are there any faults observed to truncate the unconformity. This, coupled with the general lack of internal strain observed in the Kekiktuk, suggests that the conglomerate accommodates the same amount of Brookian shortening as the underlying pre-Mississippian rocks. This is consistent with observations from other parts of the northeastern Brooks Range by Wallace and Hanks (1990), but is inconsistent with observations very near this study area by Oldow and others (1987), who noted areas both of no shear and of "substantial shear" along the unconformity.

Preliminary conclusions

Observations from the SCDA require modification of the constant-area assumption of our current model (Homza and Wallace, in review) and may or may not require modification of the kinematic consequence of our model: hinge migration kinematics. These issues are discussed separately below.

1) The presence of significant penetrative solution cleavage in the Kayak Shale in the core of the anticline strongly suggests that there was a component of mass-movement out of the core of the SCDA during fold formation. If this is true, then the modeling assumption of constant cross-sectional area is invalid here. The significance of this will be more fully understood when thin-section analyses provide quantitative estimates of the amount of area that was lost to solution.

2) There is excess material within the Kayak Shale in the anticlinal core of the fold that cannot be accounted for elsewhere. That is, there is not an observed area deficiency elsewhere in the Kayak (this deficiency may exist beneath the forelimb of the SCDA, but this area is not exposed). This geometry is relatively consistent with a

hinge-migration kinematic model for detachment folds since a linear increase in limb-length as shortening increases could accommodate the excess area without a decrease in area beneath the limbs or adjacent synclinal hinges. In contrast, the observation of no apparent overprinting relationships between hinge and limb structures in the Lisburne Limestone of the SCDA suggests that the hinges of the SCDA did not migrate since a) the current anticlinal forelimb synclinal hinge zones display penetrative and irreversible strain, and b) evidence of similar strain (i.e. tight folds, penetrative cleavage) would be expected to be overprinted in fold limbs by structures indicative of limb deformation if hinges migrated. This observation argues for a fixed arc-length kinematic model for the SCDA. Thus, it is not clear whether the SCDA evolved only by a fixed arc-length process or by a combination of fixed arc-length and migrating-hinge processes, but at least two hinges appear to have been fixed during folding. Future detailed modeling including strain data may clarify this uncertainty.

SUMMARY AND FUTURE RESEARCH

The Straight Creek Detachment Anticline (SCDA) is a well-exposed detachment fold at the headwaters of Straight Creek in the northeastern Brooks Range. This study of the SCDA has produced much useful data about the geometry and kinematics of detachment folds. These data are presented here in the form of a preliminary balanced cross section of the SCDA. Strain analyses are not yet complete and thus, are not incorporated in the present cross section.

Study of the SCDA represents the first stage in a general study of detachment folds and the information gleaned from the SCDA will provide important constraints concerning the geometry and kinematics of detachment folds. The results thus far suggest that the folding occurred mainly by flexural-slip, that the fold evolved with at least some fixed hinges, and that at least one of the common geometric assumptions about detachment folds (i.e. constant area) may be invalid.

Data obtained at Straight Creek will be incorporated with similar data from other detachment folds in the northeastern Brooks Range. All of this information will be used in an iterative modeling process involving modification of the assumptions of our current model (Homza and Wallace, in review) in order to develop an actualistic quantitative geometric and kinematic model (or models) for detachment folds. Such a model may be used to provide constraints on the evolution of fold-and-thrust belts worldwide and to better define the geometry of common structural hydrocarbon traps.

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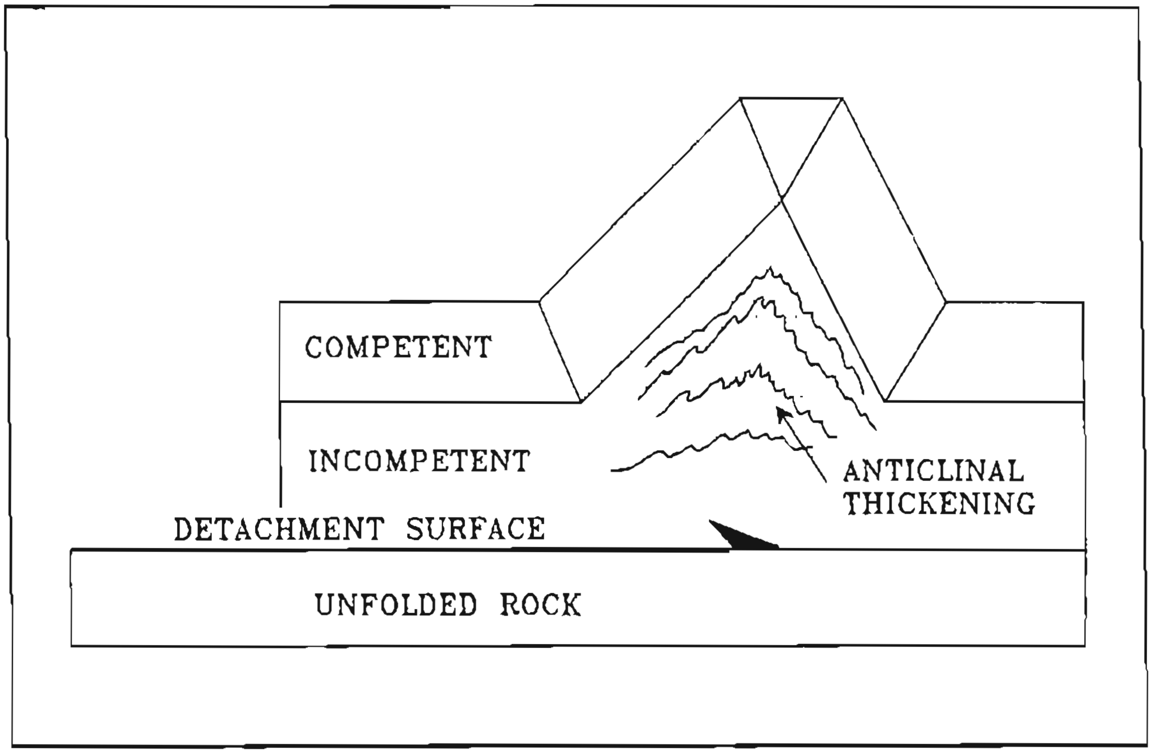

Figure 1. Schematic diagram showing the essential elements of a detachment fold.

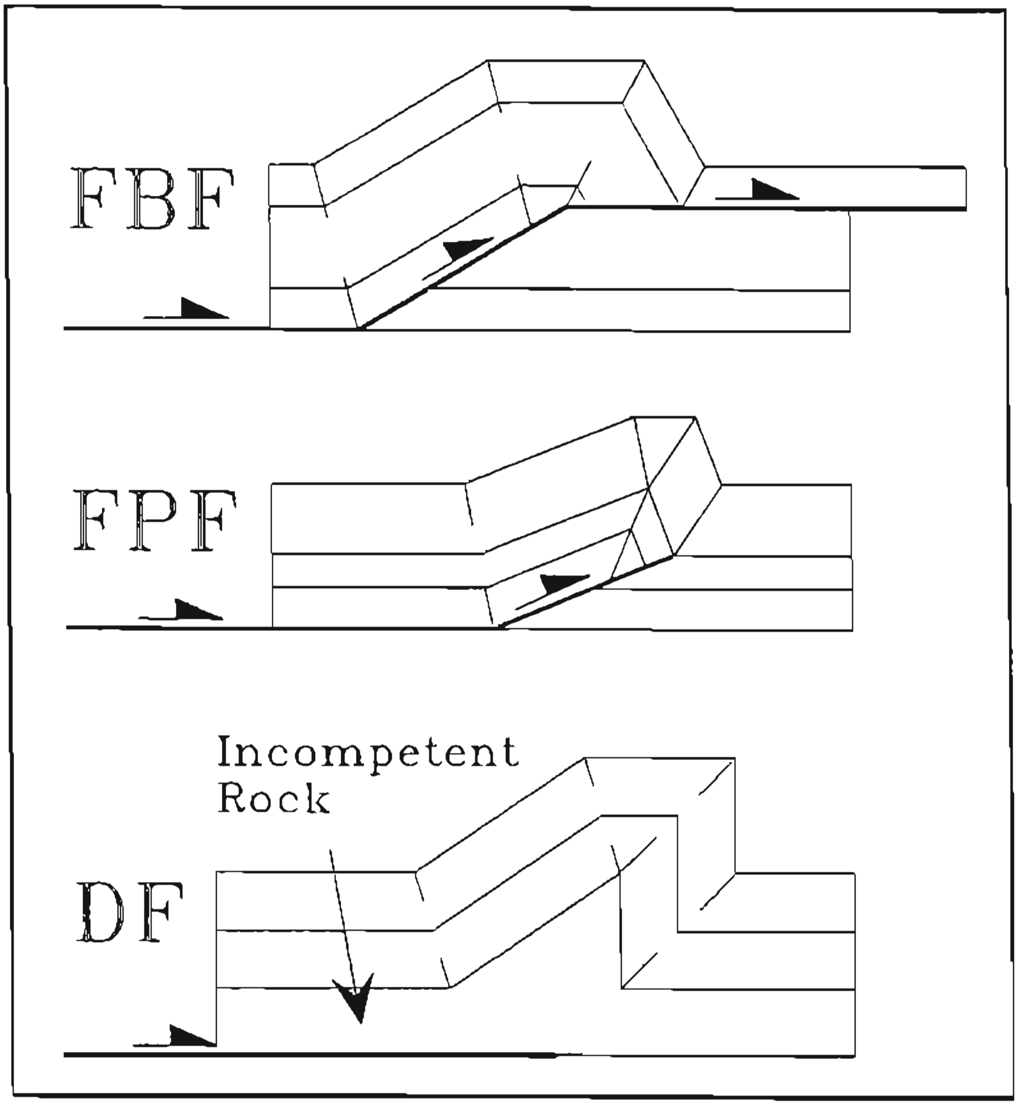

Figure 2. Three generic types of thrust-related folds in fold-and-thrust belts: Fault-bend folds (FBF), fault-propagation folds (FPF), and detachment folds (DF).

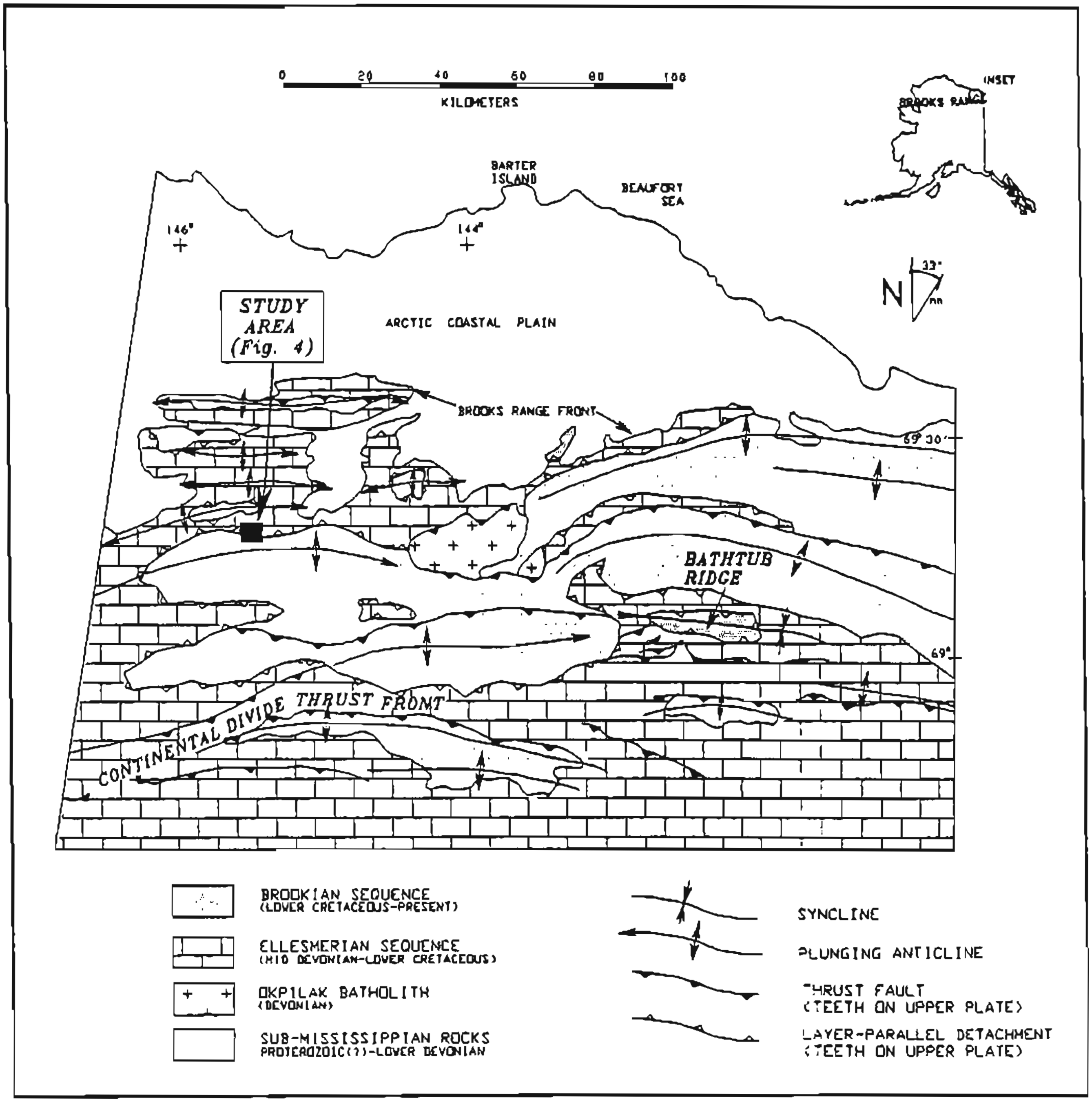

Figure 3. Tectonic map of the northeastern Brooks Range, showing location of the study area.

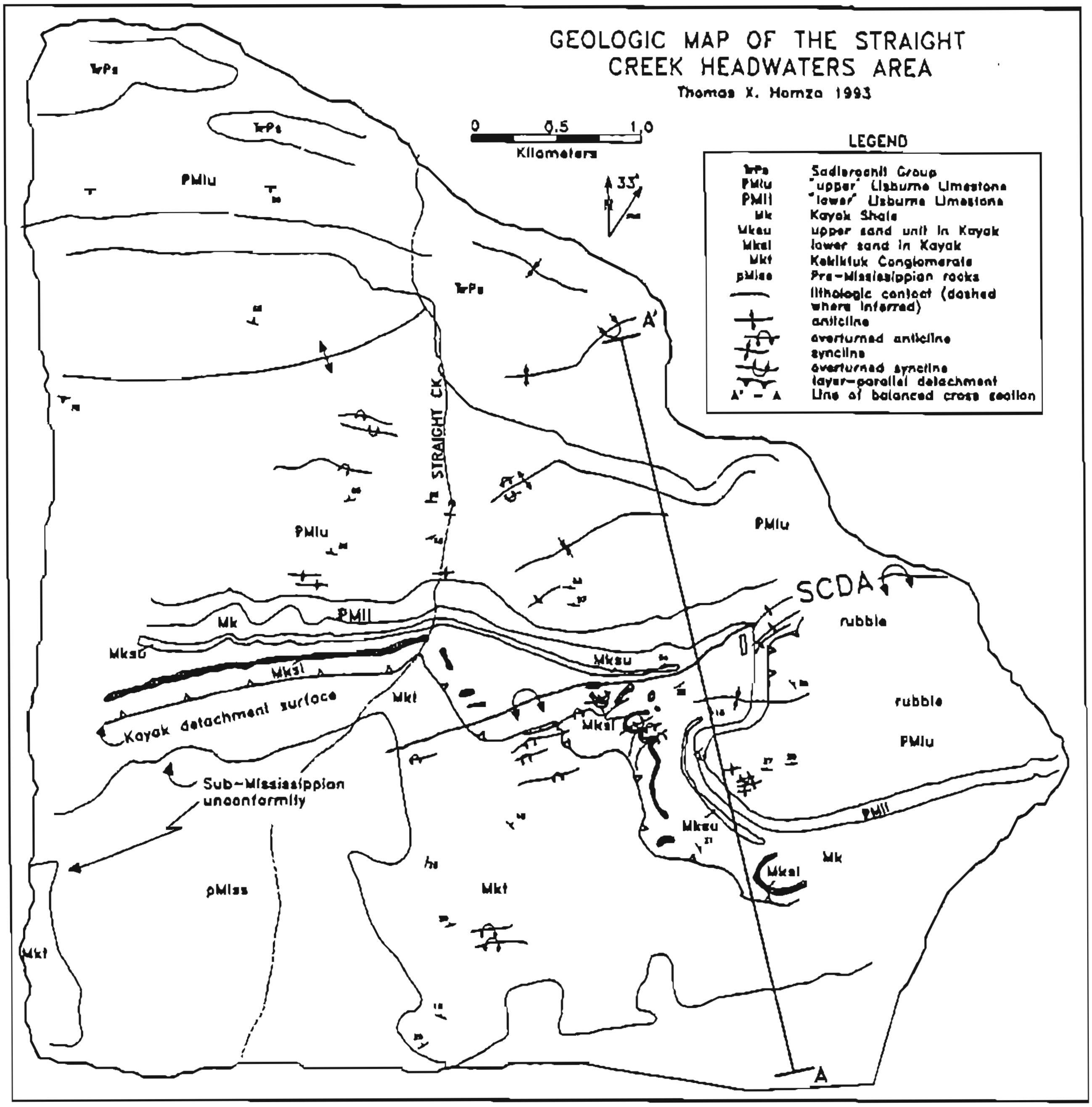

Figure 4. Geologic map of the headwaters area of Straight Creek. Shaded unit is lower competent siliceous unit in Mississippian Kayak Shale. See figure 5 for cross section along line A-A'. See figure 6 for structural stratigraphy.

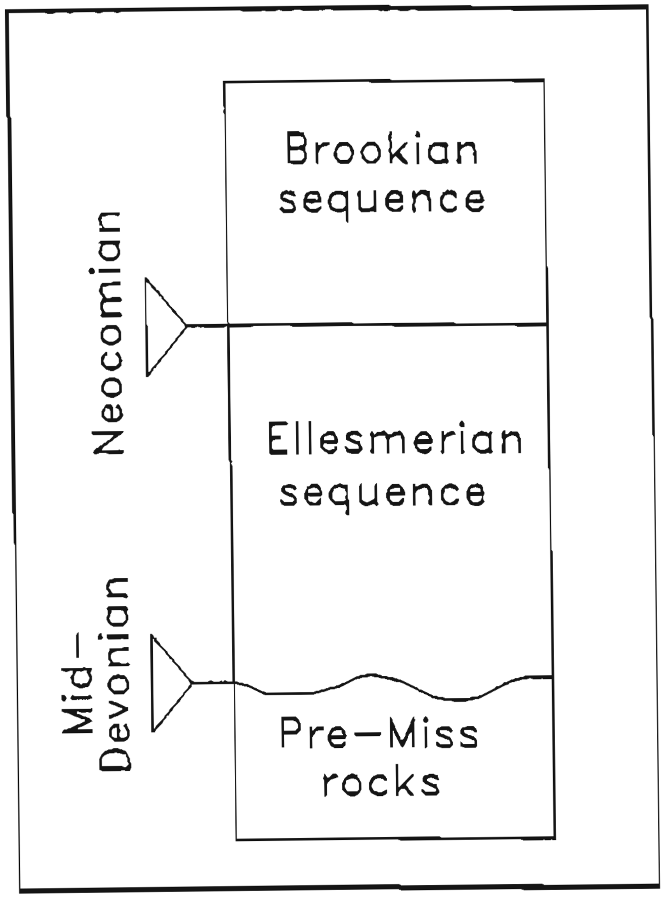

Figure 5. Stratigraphic column of the 3 general sequences of rock in the northeastern Brooks Range.

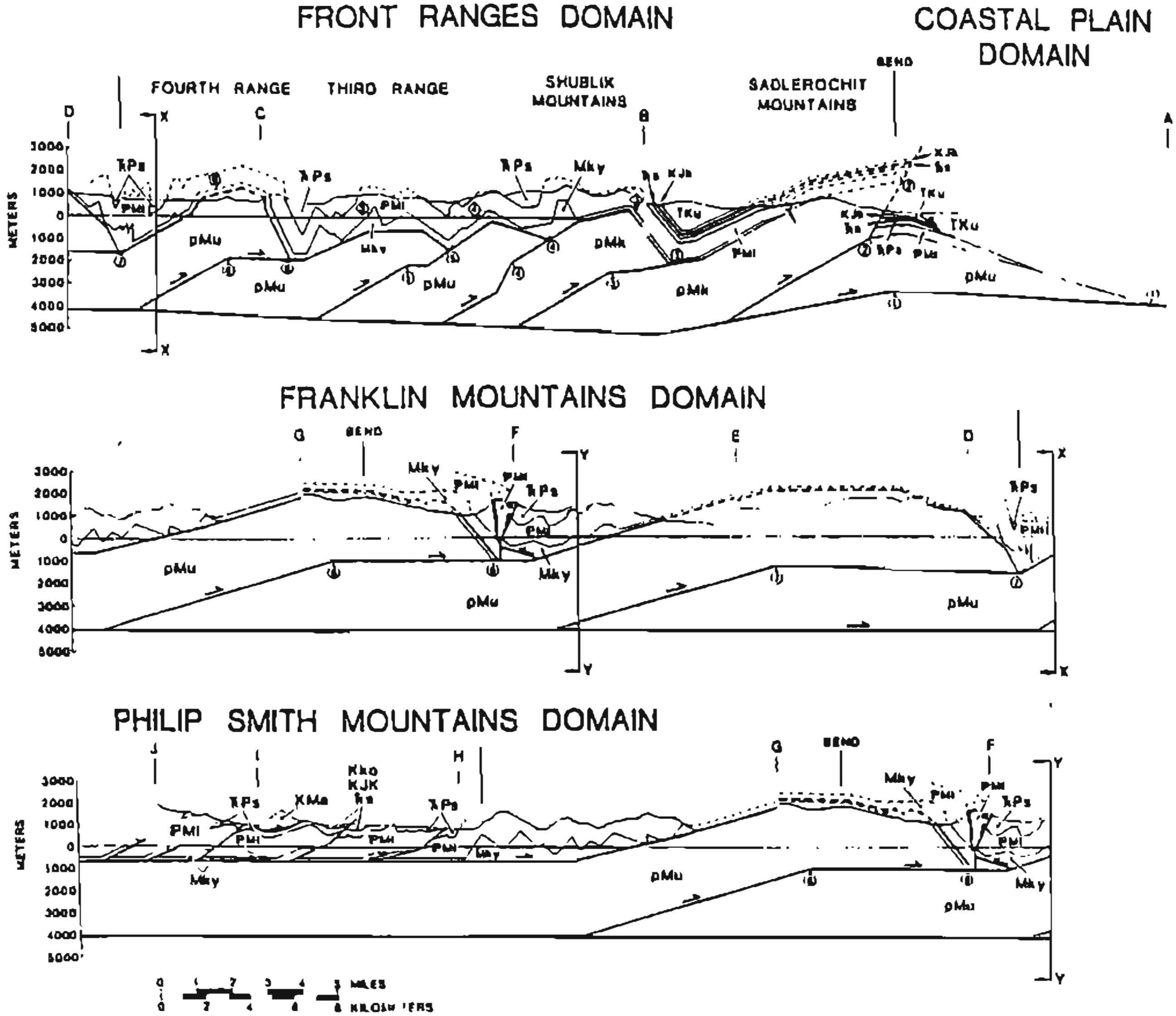

Figure 6. Balanced cross section across the western structural province of the northeastern Brooks Range (Wallace and Hanks, 1990). Section is from the continental divide area (Fig. 1.) north to the coastal plain. From Namson and Wallace, 1986.

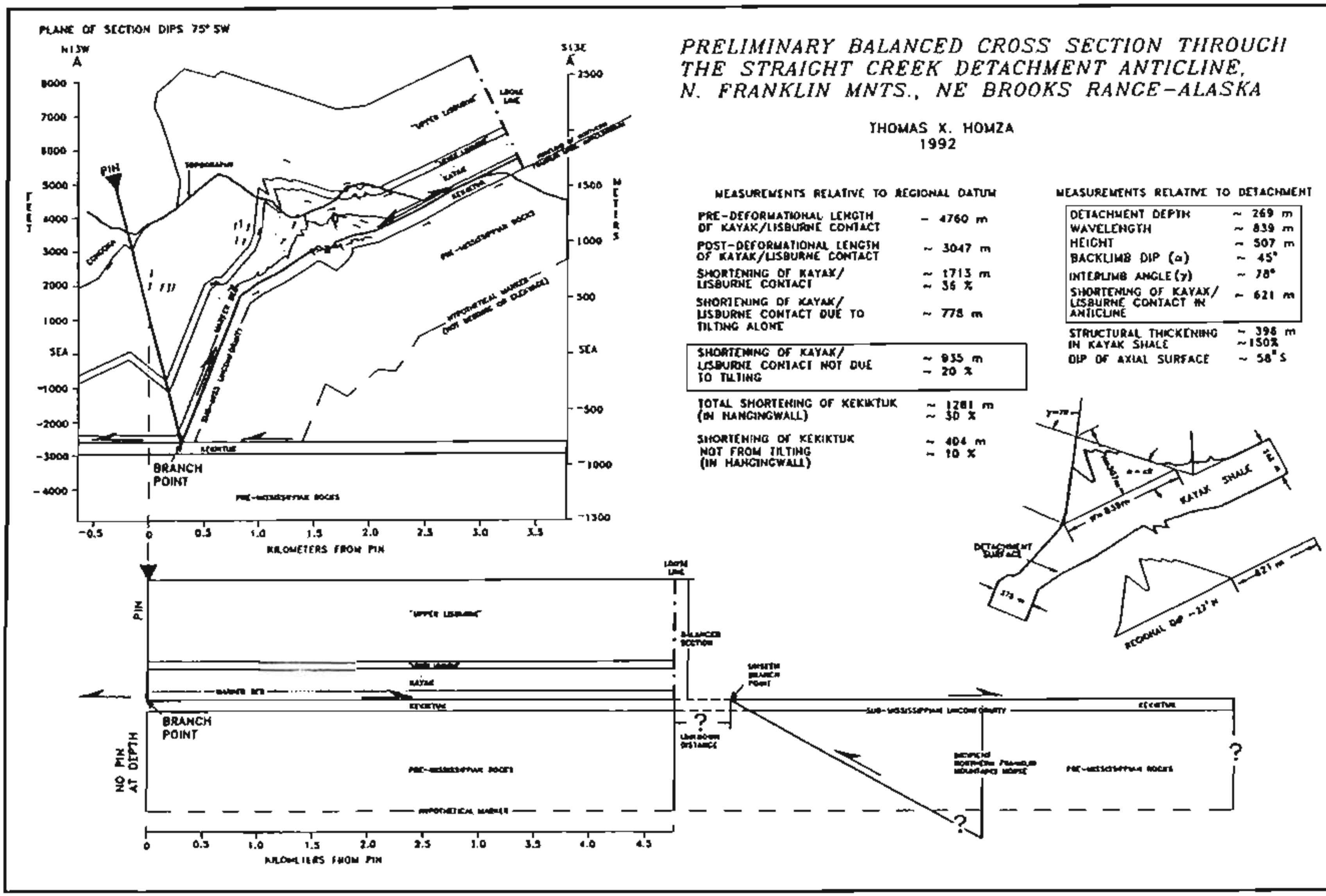

Figure 7. Preliminary balanced cross section of the Straight Creek detachment anticline. See figure 4 for line of section. Strain data is not included in this section so shortening values are considered minimum estimates.

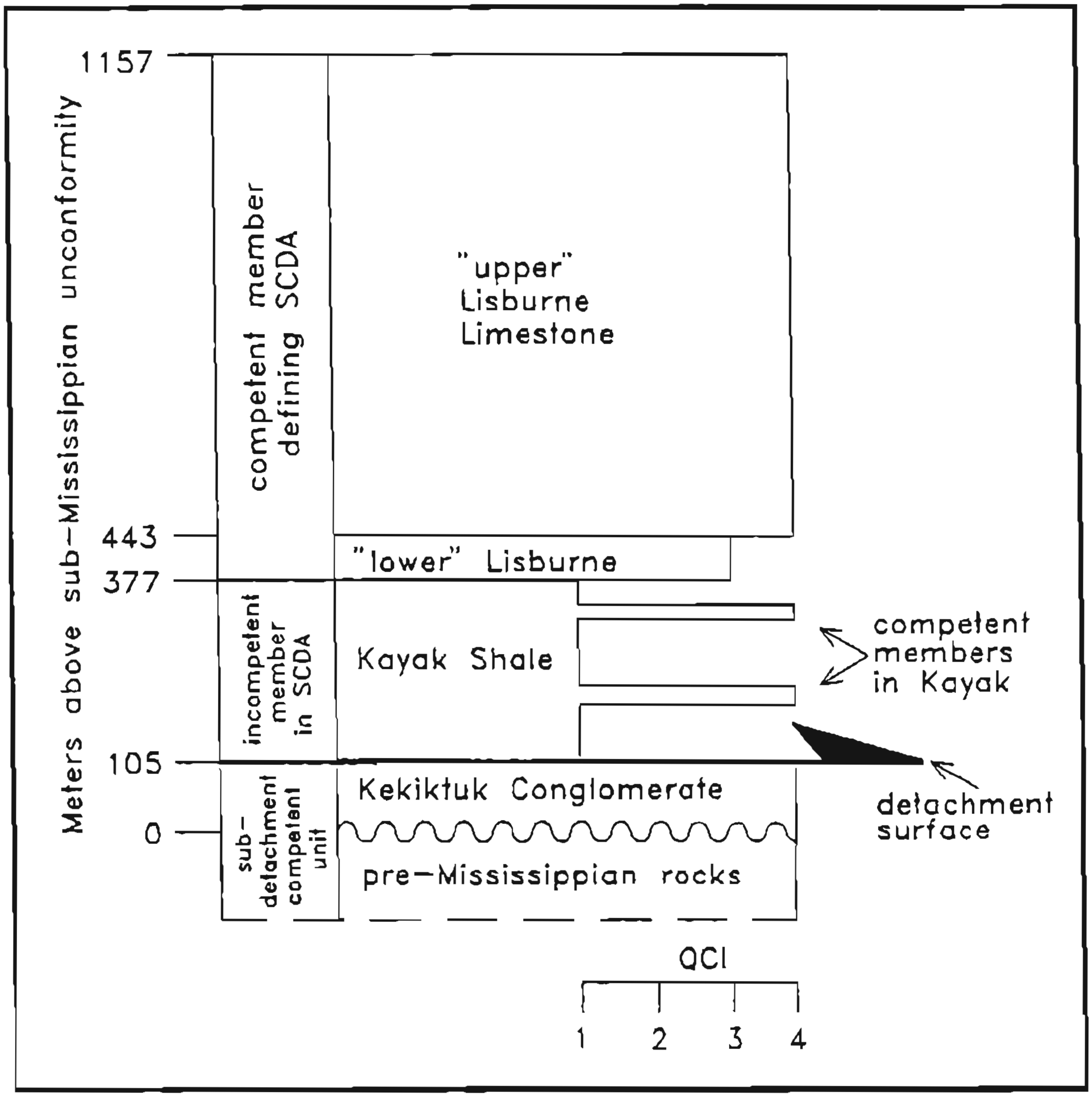

Figure 8. General stratigraphic column of structural stratigraphy in the Straight Creek headwaters areas. QCI = Qualitative competency index, larger values indicate more competent units. That is. a QCI of 1 means the unit has between 0 and 25% competent beds and that the average thickness of the competent beds is less than 0.25m. A QCI of 4 is used to describe a unit made up of more than 75% competent beds that are greater than 0.25m thick. QCIs of 2 and 3 are of intermediate competency (after Homza 1992a).

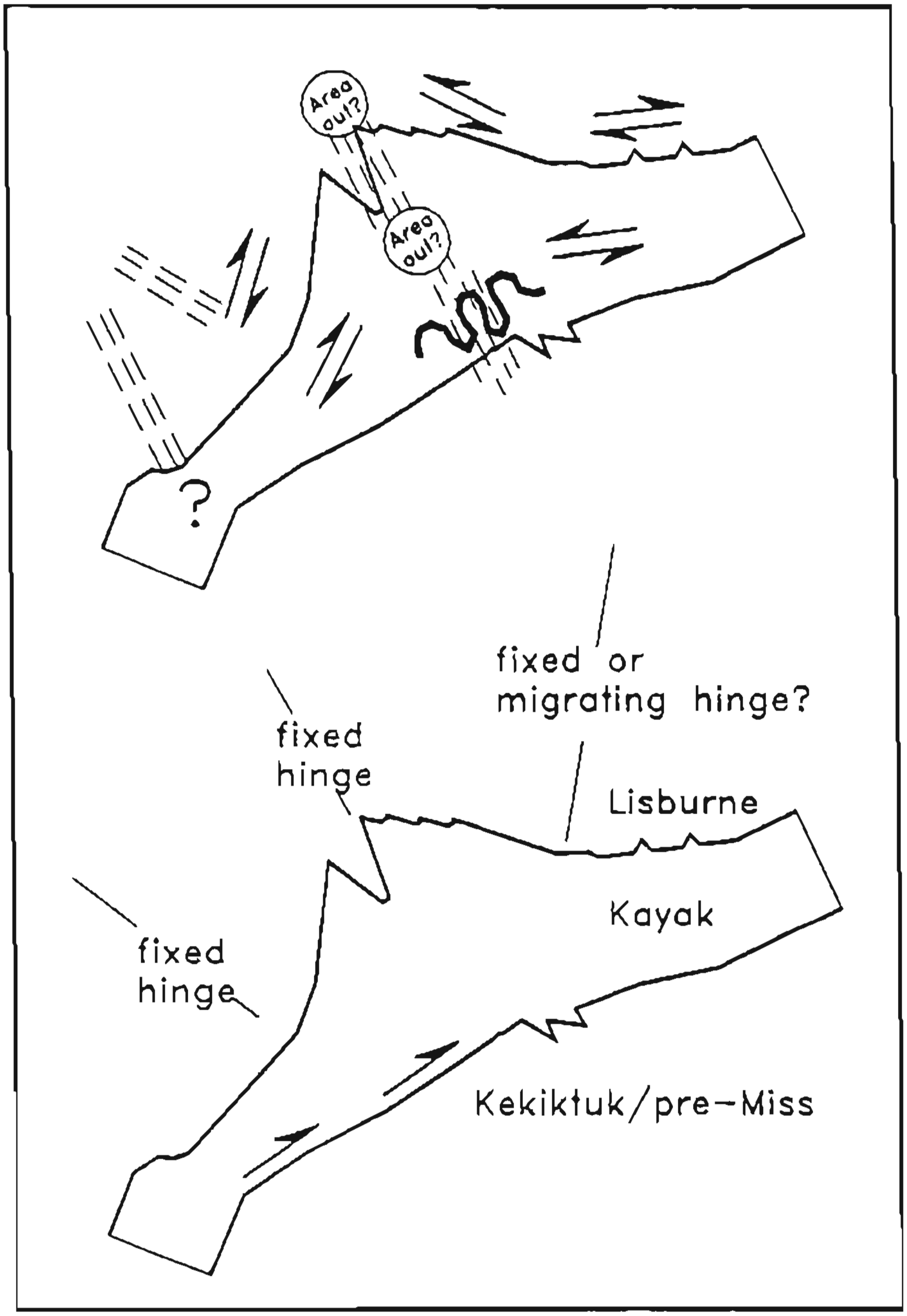

Figure 9. Diagrammatic sketch of the distribution of the significant outcrop-scale structures observed across the Straight Creek detachment anticline (upper sketch) and the interpreted kinematic constraints imposed upon the modeling process by these observations (lower sketch).

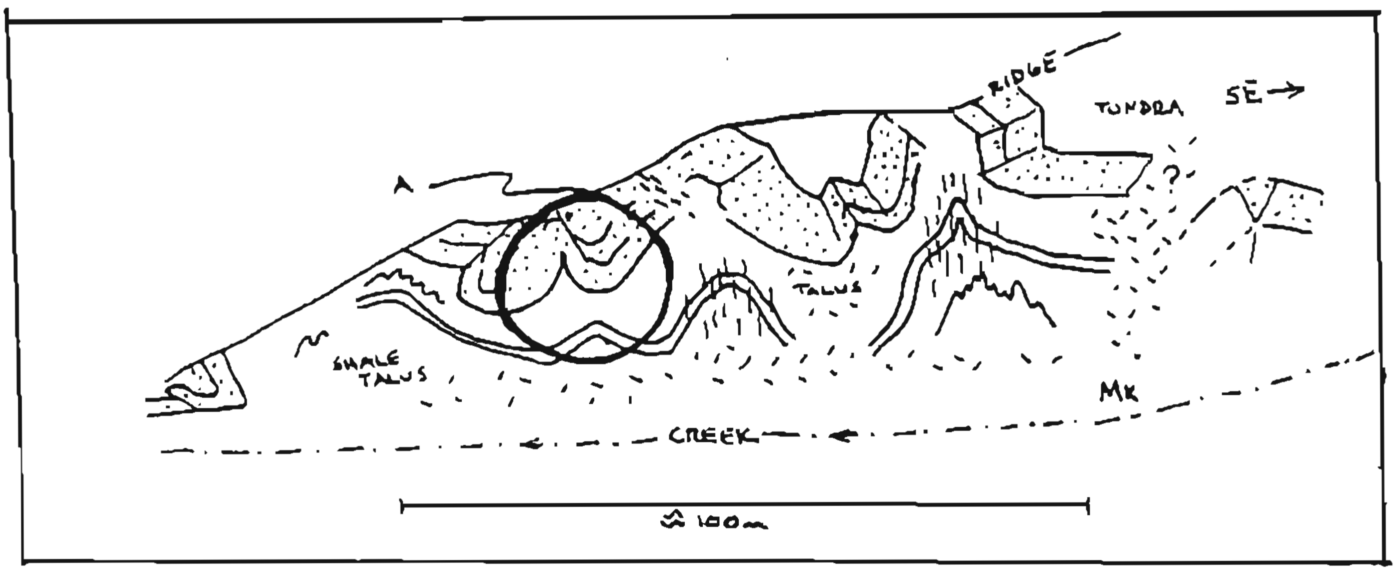

Figure 10. Sketch of the folds observed in the lower siliceous unit of the Kayak Shale observed in the lower parts of the core of the Straight Creek detachment anticline. Area A is shown in figure 12.

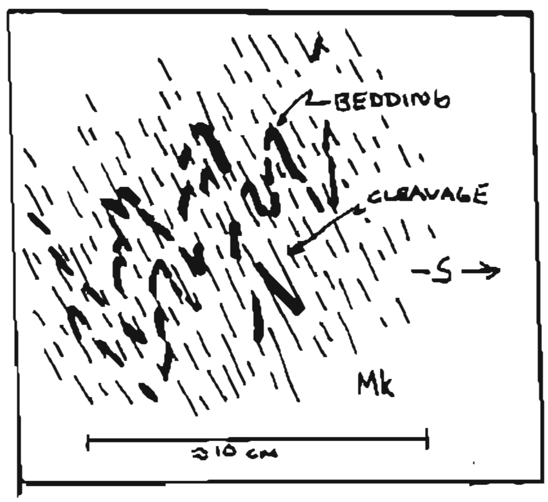

Figure 11. Sketch of transposed bedding observed in the shale units in the upper parts of the Kayak Shale in the core of the Straight Creek detachment anticline.

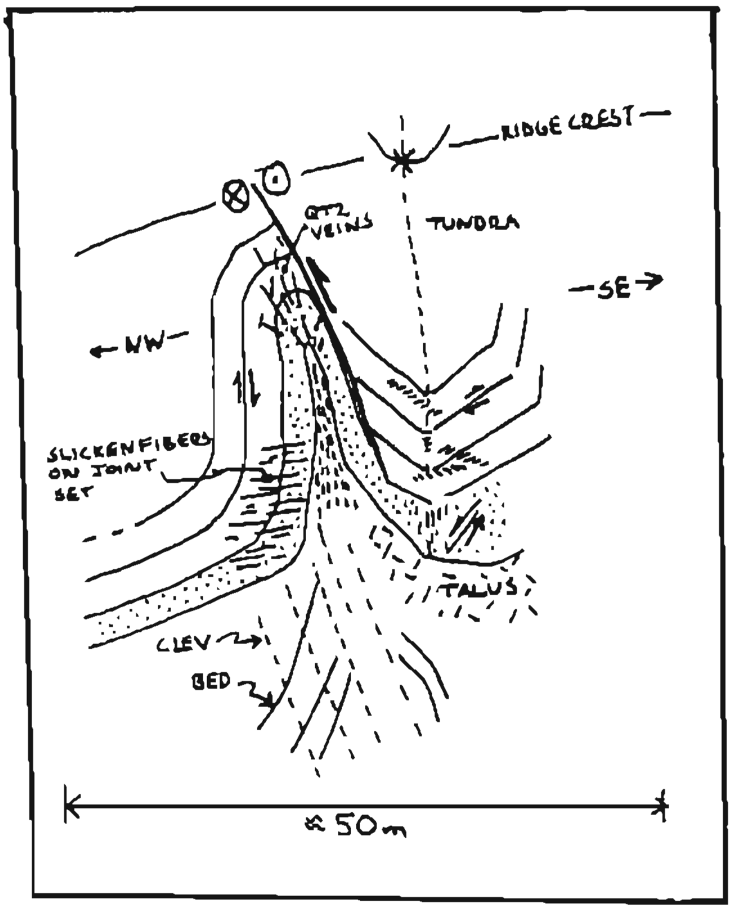

Figure 12. Sketch showing an example of the distribution of structures associated with the tight folds of the lower siliceous unit of the Kayak Shale (Fig. 10).

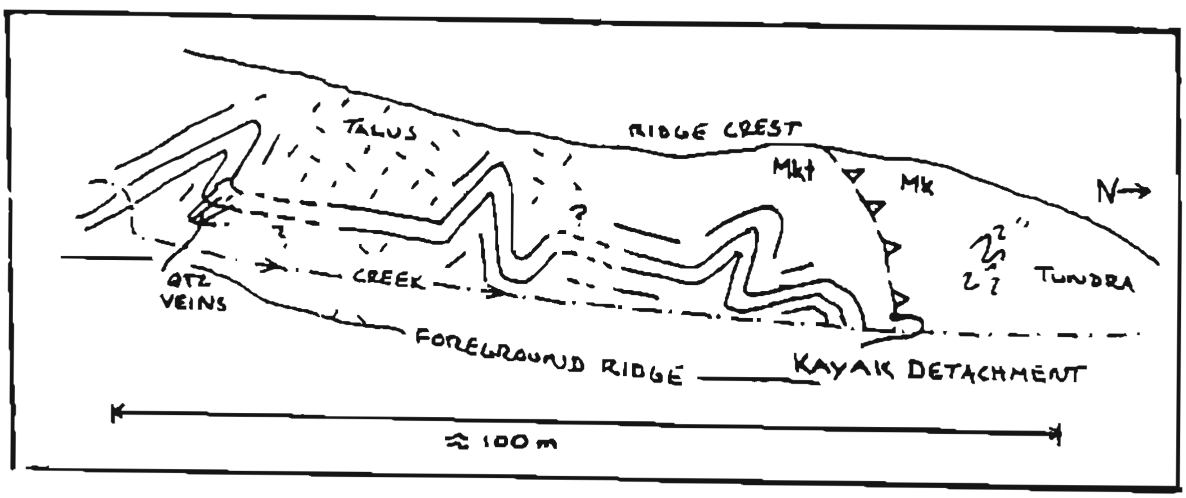

Figure 13. Sketch of the tight folds observed in the upper Kekiktuk Conglomerate beneath the detachment horizon in the Kayak Shale.

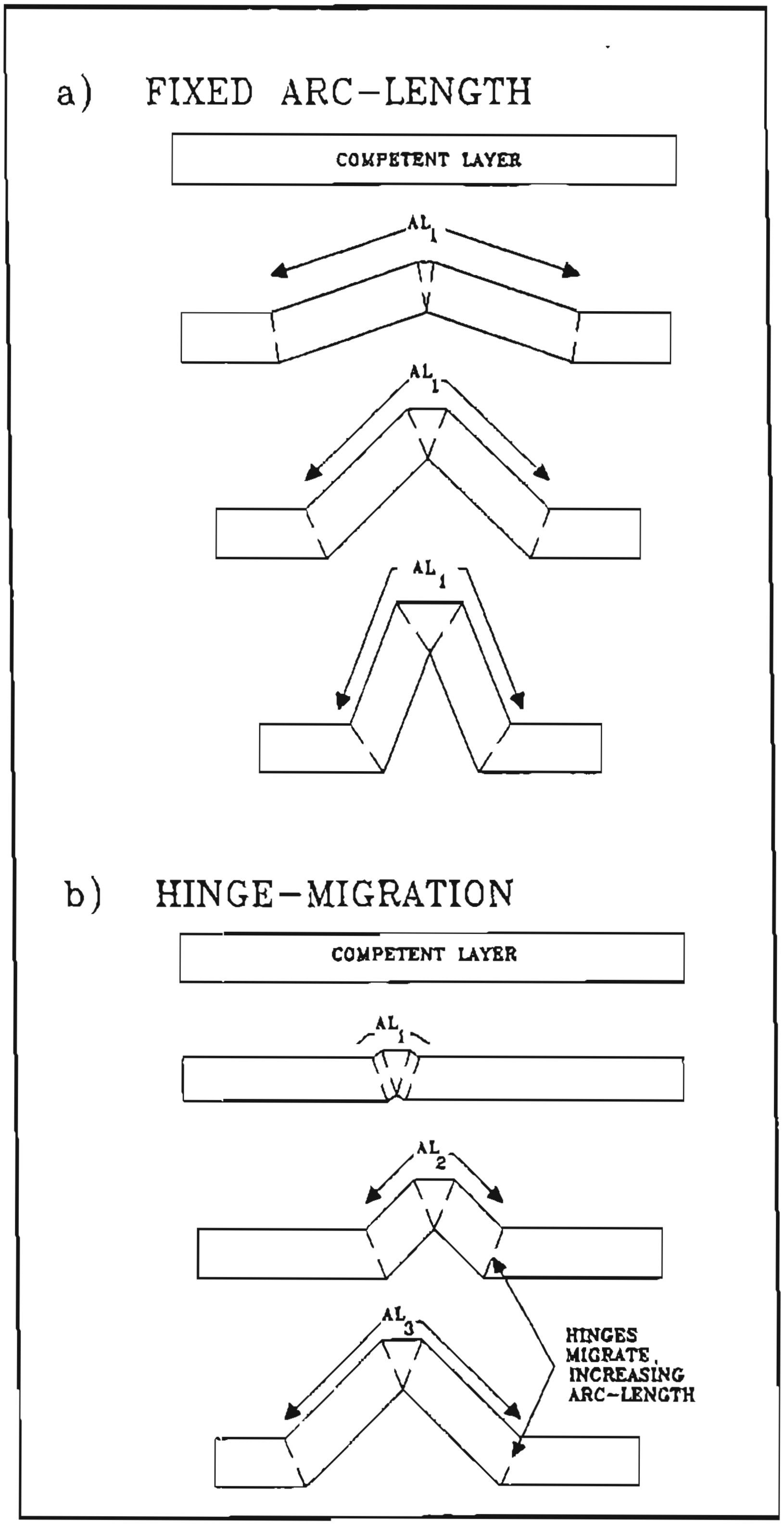

Figure 14. Diagram illustrating the kinematic distinction between fixed-arc length folding and migrating-hinge folding. Migrating hinge kinematics suggests the existence of overprinting relationships on the limbs of folds (limb structures overprinting hinge structures).

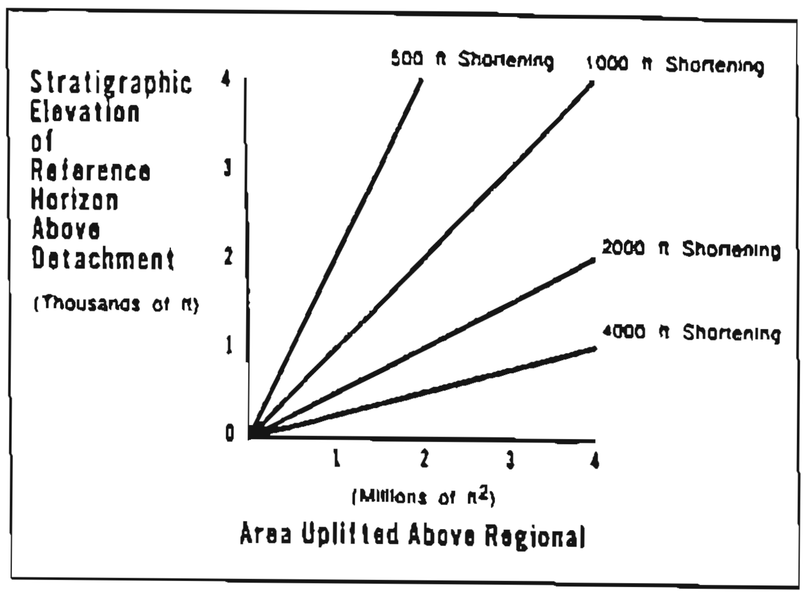

Figure 15. Linear relationship among shortening (S), detachment depth (D), and area uplifted beneath an idealized detachment anticline (A) (SD=1/2(A)). From Dahlstrom (1990).

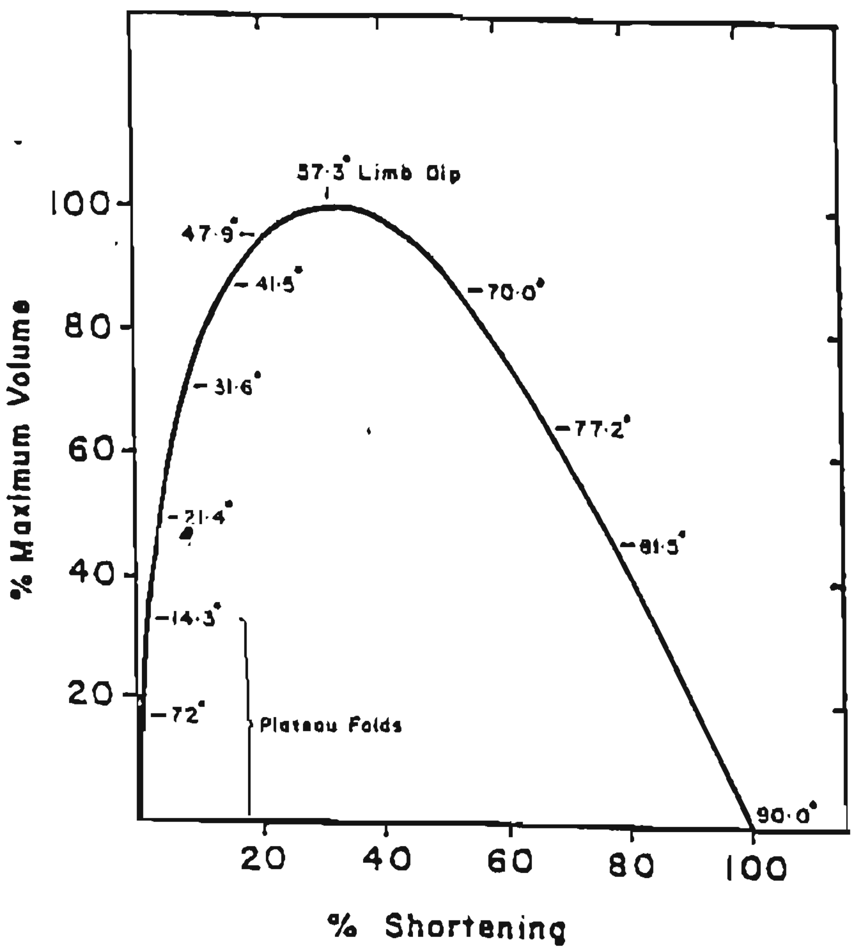

Figure 16. Non-linear relationship between cross-sectional area and shortening for a fixed arc-length fold (From Wiltschko and Chapple, 1977).