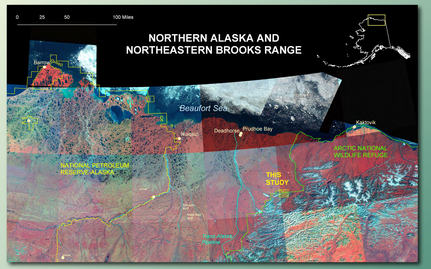

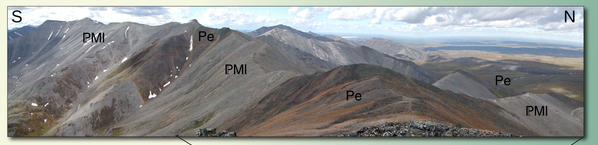

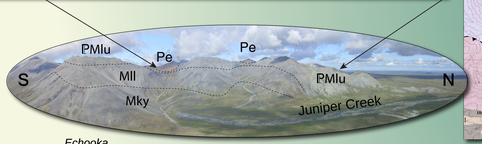

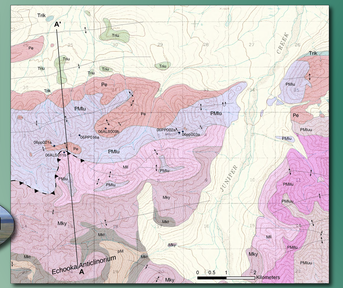

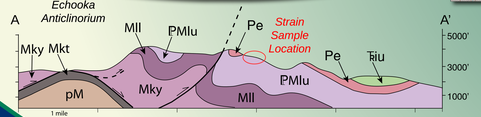

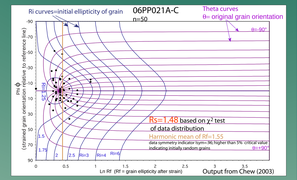

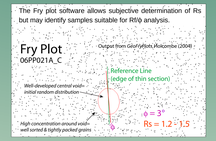

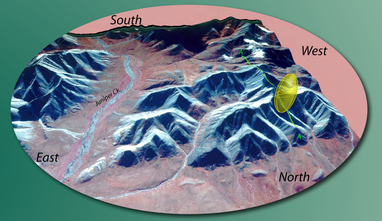

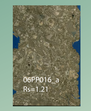

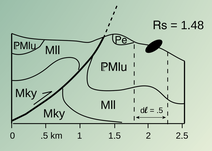

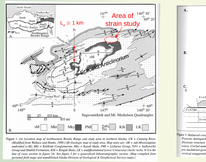

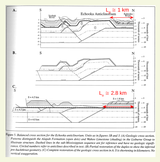

Strain analysis of elliptical grains from a fold and thrust belt, Kavik River area, northeastern Alaska

A RUDIMENTARY EFFORT TO APPROXIMATE PENETRATIVE SHORTENING AND TO GENERATE INTEREST IN QUANTIFIED STRAIN ESTIMATES FOR NORTHEASTERN ALASKA

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Strain analysis of elliptical markers provides an estimate of the finite strain ellipse shape. Subsequent strain integration parallel to principal transport direction provides an estimate of shortening due to penetrative strain. Ongoing geologic studies in the petroleum province of northern Alaska aim to characterize and quantify shortening in the Brooks Range fold and thrust belt. Balanced cross-sections are commonly used to estimate shortening, but this method ignores penetrative strain. Strain markers from the Mississippian-Pennsylvanian Lisburne Group were analyzed by the Rf/ϕ method to quantify the penetrative component of shortening in these units. Samples with appropriate random and anti-clustered grain distributions were identified using the center-to-center Fry technique. Thin sections from oriented field samples included ooids, calcispheres, and crinoid columnals from the Lisburne. Three orthogonal sections from each sample were cut in order to determine the local three-dimensional strain if possible. A symmetry test assessed the assumption of original symmetry of grain distributions and identified samples likely to have had pre-strain sedimentary or tectonic fabrics. Integration of strain values across local structures provides an estimate of penetrative shortening that can be added to values from balanced cross sections, providing a closer approximation of total shortening.

LOCATION & GEOLOGIC SETTING

- ▭ Qu surficial deposits
- ▭ T̵riu undifferentiated Ivishak Fm
- ▭ T̵rik Kavik Mem. of Ivishak Fm
- ▭ Pe Echooka Fm
- ▭ PMlu upper Lisburne LS
- ▭ PMllu lower upper Lisburne LS
- ▭ PMluu uppermost Lisburne LS
- ▭ Mll lower Lisburne LS
- ▭ Mky Kayak Shale
- ▭ MKt Kekiktuk Conglomerate
- ▭ pM pre-Mississippian rocks

Schematic cross-section A-A'. Lisburne Limestone has been simplified into lower and upper units.

The field area lies within the foothills of the northeastern Brooks Range, a north-vergent fold and thrust belt. Pre-Mississippian metasedimentary rocks form the cores of regional anticlinoria within a passive roof duplex (Wallace and Hanks, 1990). Mississippian and younger rocks deform independently above a detachment in the Kayak Shale. Strain samples were collected from the passive margin carbonates of the Lisburne Limestone.

Eliminated Samples

Despite obvious planar strain at hand sample and outcrop scale, three carbonate samples were eliminated on the basis of grain size and the lack of measurable markers.

One sample from the Echooka sandstone was eliminated because the assumption of original ellipticity of grains could not be reliably met.

06pp021A was an unoriented sample. It was collected because the strain markers were extremely well developed. The "A" thin section was cut parallel to cleavage. Slaty cleavage was assumed to be parallel to the x-y plane of the strain ellipsoid (Ramsay and Huber, 1983). Because the sample was collected from the north side of a north-vergent syncline, we assumed (in absence of an actual measurement) that cleavage dips south more steeply than bedding. The "C" thin section was therefore roughly parallel to the x-z plane, the plane of our cross-section A-A', and the z axis plunges north. The resulting ellipsoid is prolate and is consistent with north-south compression. Symmetrical Rf/ϕ plots suggest no pre-strain sedimentary fabrics were present.

Output from Chew (2003)

The Fry plot software allows subjective determination of Rs but may identify samples suitable for Rf/ϕ analysis.

STRAIN ANALYSIS

We were successful using the Rf/ϕ technique to calculate Rs values and in using them for strain integration. Statistical analyses associated with the method allowed significant confidence in our methods. However, subsequent studies will require more thoughtful sampling of a greater number of samples. Samples should be oriented with respect to local structures (i.e., slaty cleavage) and not bedding in order to allow more straightforward interpretation of the strain ellipsoid. Sample 016 (below) may still be incorporated into the analysis if and when the principal plane ellipticities can be calculated.

The Fry plot analysis was a useful tool for confirming the assumption of originally random grain distributions. However we found the visual Rs determination somewhat subjective.

A greater number of Rs values are needed to properly integrate across a greater number of structures. Also, measurements made on samples from different structural levels will allow a more robust interpretation of penetrative strain from mechanically distinct units.

Sample 06pp016 was oriented. The "A" section is parallel to bedding (081, 50S). The cross-section line trends 174. The "B" thin section was cut parallel to strike. The orthogonal "C" thin section is roughly parallel to the cross-section A-A'. However, these samples do not represent any of the principal planes of the strain ellipsoid. The ellipsoid shape could be derived from these sections (Ramsay, 1967).

STRAIN INTEGRATION

To determine an initial estimate for penetrative shortening, we integrated the reciprocal elongation across a portion of our cross-section (Hossack, 1978). We used the Rs value of the x-z principal plane, parallel to our cross-section and parallel to regional transport.

Stretch S = deformed length/original length = L_d/L_o

Elongation $\lambda = S^2$

For z-axis of ellipsoid (maximum compression):
$\lambda_z = S_z^2 = 1/Rs$ (Ramsay, 1967)
$\sqrt{\lambda_z} = S_z = \sqrt{1/Rs}$
Reciprocal elongation $\sqrt{\lambda'_z} = \sqrt{Rs}$

$L_o = \int \sqrt{\lambda'_z}\, d\ell = \int \sqrt{Rs}\, d\ell$

Integrating between $\ell = 1.8$ and $\ell = 2.3$ ($L_d = .5$)
where Rs = 1.48 ($\sqrt{Rs} = 1.22$), $L_o = 1.22(2.3 - 1.8) = .61$ km

Shortening = $L_o - L_d = .61 - .5 =$ *.11 km*
or .11/.61 = *18%*

Figure 1. (A) Location map of northeastern Brooks Range and study area in northern Alaska. CR = Canning River. (Modified from Wallace and Hanks, 1990.) (B) Geologic map of study area. Map units are: sM = sub-Mississippian undivided (s-M), Mkt = Kekiktuk Conglomerate, Mky = Kayak Shale, PMl = Lisburne Group, TrPs = Sadlerochit Group and Shublik Formation, KJk = Kingak Shale, LK = undifferentiated Lower Cretaceous clastic rocks. N-S is the line of cross section in figure 5A. See figure 3 for a generalized lithostratigraphic section. (Map compiled from personal field maps and unpublished Alaska Division of Geological & Geophysical Surveys maps.)

Figure 5. Balanced cross section for the Echooka anticlinorium. Units as in figures 1B and 3. (A) Geologic cross section. Patterns distinguish the Alapah Formation (open dots) and Wahoo Limestone (shading) in the Lisburne Group to illustrate structure. Dashed lines in the sub-Mississippian sequence are for reference and have no geologic significance. Circled numbers refer to anticlines described in text. (B) Partial restoration of the duplex to show the inferred pre-backthrust geometry. (C) Complete restoration of the geologic cross section in A. S is shortening in kilometers. No vertical exaggeration.

TOTAL SHORTENING

Meigs and Imm (1995) discuss and quantify shortening in the Echooka River area and present balanced and restored cross sections. They estimate minimum total shortening in the roof strata as 4.5 km, with 1.8 km of this accommodated by folds and faults north of the Echooka Anticlinorium (see above, from that paper). These structures are along strike and equivalent to the features in this strain study.

Our trial estimate of shortening only accounts for shortening within the x-z plane, with no movement out of the plane of section. 1.8 km of shortening equates to about 64% accommodated by macroscale structures in this localized zone. Including penetrative shortening results in a minimum shortening of 82%. Is this reasonable?

This is not a comprehensive treatment of penetrative strain. Many authors suggest ways to refine the techniques used here. We hope to see additional work in the northeastern Brooks Range.

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