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TEMPORAL - SPATIAL EVOLUTION OF TERTIARY DEFORMATION, BEAUFORT SEA - MACKENZIE DELTA REGION

INTRODUCTION

The Beaufort-Mackenzie Region includes the Beaufort Foldbelt, an offshore foreland element of the Cordilleran orogen, comprising a thin-skinned fold and thrust belt involving syntectonically deposited Tertiary sediments of the Beaufort Sea continental margin. This important frontier petroleum province contains recoverable reserves of 1.5-2 billion barrels of oil and 12 trillion cubic feet of natural gas in 53 significant discoveries (Dixon et al., 1994). A 216 km crustal-scale depth-converted cross-section through the central Beaufort Sea incorporates industry seismic and well data, and GSC crustal structure data (Dietrich et al., 1989; Lane and Dietrich, 1991; Stephenson et al., 1994).

The cross-section is divisible into three segments whose boundaries are based on observed variations in age, amplitude and style of structures. Bed length calculations were made for four levels in the Tertiary part of the section: Late Miocene, Late Oligocene and Middle Eocene unconformities, and within the Paleocene Aklak sequence. The calculations are based on regionally resolvable structures and measure only thrust duplication and folding. Additional shortening on small-scale structures and by layer-parallel shortening imply that the shortening estimates are conservative.

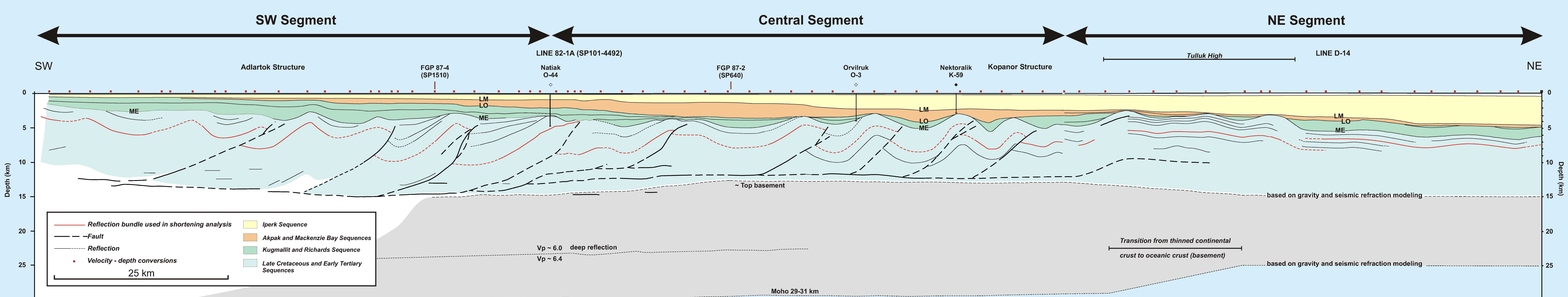
Total measured shortening is 14.5% (37 km). Pre-Middle Eocene shortening of 30 km is confined to the two inner segments of the profile, and is dominated by thrust duplication. Late Eocene to Oligocene shortening of 6 km is accommodated by folding, and is concentrated in the central segment. Low amplitude Miocene folding totalling 1 km is concentrated in the outer segment.

This analysis documents that deformation was strongly concentrated in the pre-Middle Eocene part of the Tertiary, and that the locus of deformation progressed toward the foreland through time.

AGES OF LATE CRETACEOUS - TERTIARY DEFORMATION

The map of the northern Yukon, NWT and adjacent Alaska region (below) shows the principal ages of deformation superimposed on regional structural trends (Lane, 1998). Deformation ages for the offshore Beaufort Foldbelt are based on seismic stratigraphy (Lane and Dietrich, 1995, 1996); ages for the Brooks Range and Yukon north of 67° N are based on apatite fission track cooling ages; ages for the Yukon farther south are based on published and unpublished biostratigraphic control (e.g., Dixon, 1992). One small isolated area in the south showing a Paleocene age reflects a new, unpublished fission track cooling age.

In general the age progression, reflecting the dominant event in each area, shows a younging trend from latest Cretaceous and Paleocene in the hinterland to Miocene in the foreland. The offshore data indicate that the deformation was episodic (Lane and Dietrich, 1995). Note that the Late Cretaceous age brackets in the south reflect the lower resolution of the biostratigraphic data. Facies and thickness trends of Late Cretaceous strata from Eagle Plain indicate that deformation post-dates deposition of the Eagle Plain Group, which is as young as Campanian in age (Dixon, 1992; Lane, 1996).



SHORTENING (SW)

POST-LATE OLIGOCENE (LO) 0.2 km (0.3%)
MIDDLE EOCENE (ME) - LATE OLIGOCENE (LO) 1.0 km (1.3%)
PRE-MIDDLE EOCENE (ME) 16.3 km (18.1%)
TOTAL 17.5 km (19.4%)

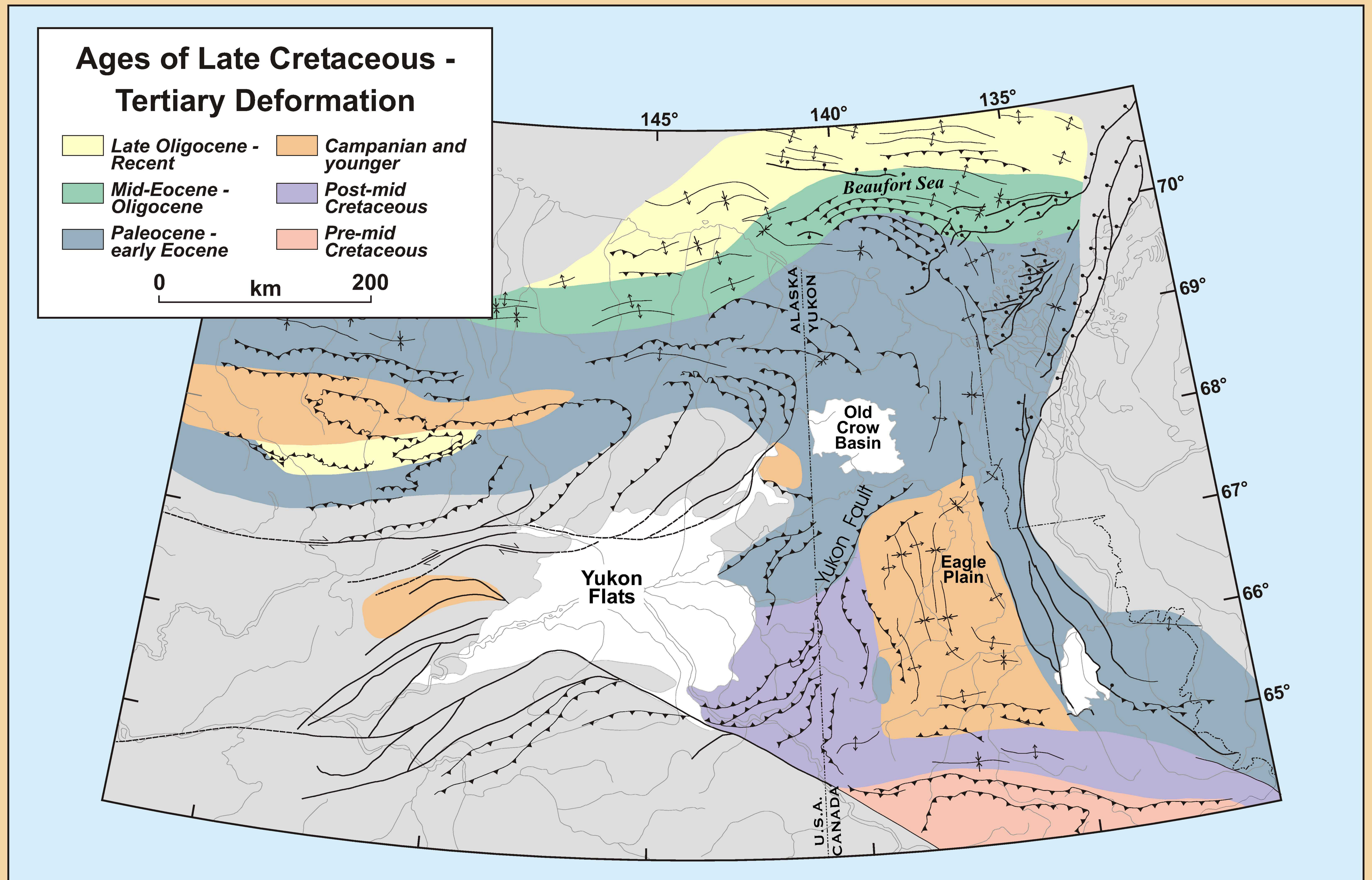
SHORTENING (CENTRAL)

POST-LATE OLIGOCENE (LO) 0.2 km (0.3%)
MIDDLE EOCENE (ME) - LATE OLIGOCENE (LO) 3.9 km (5.0%)
PRE-MIDDLE EOCENE (ME) 13.9 km (15.0%)
TOTAL 18.0 km (19.4%)

SHORTENING (NE)

POST-LATE OLIGOCENE (LO) 0.5 km (0.8%)
MIDDLE EOCENE (ME) - LATE OLIGOCENE (LO) 1.0 km (1.4%)
PRE-MIDDLE EOCENE (ME) -0.2 km (-0.3%)
TOTAL 1.3 km (1.9%)

Ages of Late Cretaceous - Tertiary Deformation



SHORTENING CALCULATION

A crustal-scale cross-section across the Beaufort Foldbelt was constructed from two industry seismic reflection lines. The cross-section was divided into three segments for this analysis. The southwest segment extends from the southwest edge of the section in the shallow offshore to the Natiak O-44 exploration well. The central segment extends from Natiak to the splice between the two lines. The south-east and central segments are characterized by higher amplitude detached folds disrupted by northeast-directed thrust faults which splay upward from a basal décollement. The northeast segment is characterized by low amplitude folds which show no evidence of thrust faults extending upward into the anticlinal hinges.

This quantitative analysis confirms the qualitative assessment made previously (Lane and Dietrich, 1995) that the total Tertiary shortening is about 20%, or about 35 km, for the part of the Beaufort Foldbelt underlain by high amplitude thrust-cored folds. It further confirms the obvious inference that the total shortening in the distal low amplitude region of the foldbelt is substantially less, nearly 2% or about 1.3 km. The total shortening of almost 37 km, is 14.5% when averaged over the entire 216.5 km length of the cross-section. The Paleocene to early Eocene shortening, totals about 30 km. Most shortening (16 km) occurred southwest of the Natiak well, with nearly as much (14 km) occurring in the central part of the section. In the distal northeastern part, shortening during the early Tertiary time interval is negligible. The consistency in shortening estimates for the two inner segments correlates well with the consistency of their structural styles (high amplitude, thrust-cored folds).

Duplication of the early Tertiary succession by thrust faulting accounts for much of the pre-middle Eocene shortening. In contrast, thrusting is not present in the post-middle Eocene shortening (i.e., none of the faults offsets the middle Eocene unconformity). Three of the faults override syntectonic deposits of the early Eocene Taglu Sequence (fanning reflections). The hanging walls are erosionally truncated at the middle Eocene unconformity. The horizontal shortening accommodated by thrust duplication in the southwest and central segments of the cross-section is nearly 19 km, almost two-thirds of the pre-middle Eocene shortening of 30 km.

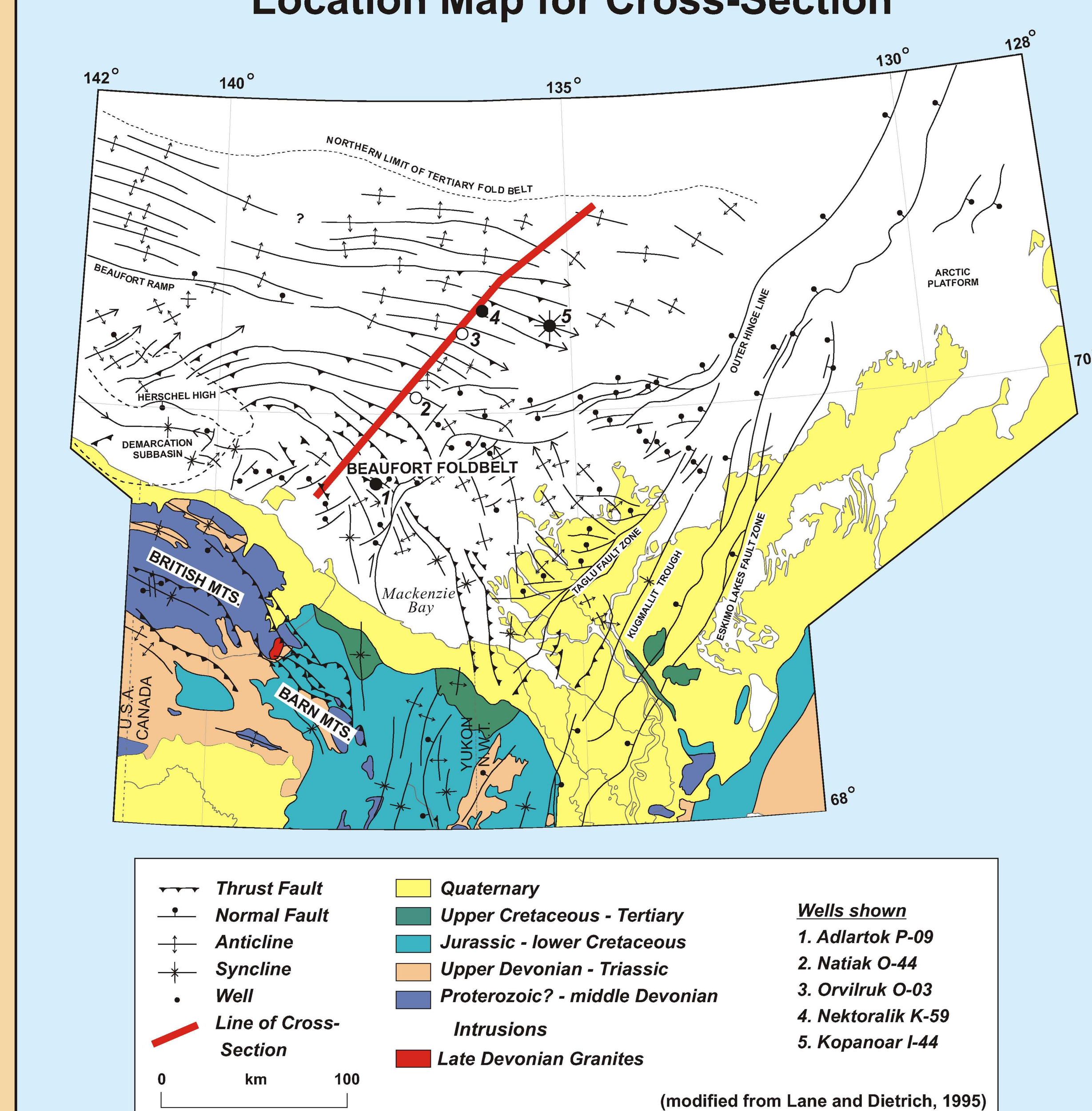
The distribution of shortening during the late Eocene to late Oligocene interval varies across all three segments from 1 km in the southwest to 4.9 km in the central segment and 1 km in the northeast, for a total of only 5.9 km. This agrees with our previous qualitative assessment (Lane and Dietrich, 1995) that little shortening occurred in inboard areas in post-middle Eocene time; and that the locus of mid-Tertiary shortening migrated toward the foreland. This is documented by the greater amplitude of folding on the middle Eocene unconformity in the central segment of the cross-section.

The late Miocene unconformity escaped perceptible orogenic shortening, and can be viewed as marking the end of orogenic activity in the area of this cross-section. The measured lengths of this surface are essentially identical to the horizontal lengths of each segment of the cross-section, varying by no more than 110 m in each segment. The measured variations in individual segment lengths cancel out over the total section so that both the horizontal distance and the length of the late Miocene unconformity measure 216.5 km. Accordingly, differences on the order of 100 m must be considered as random errors arising from digitizing the cross-section.

Because negligible shortening postdates the late Miocene unconformity, the shortening calculated on the late Oligocene unconformity represents the interval from late Oligocene to late Miocene time. In the late Oligocene to late Miocene interval (essentially the Miocene Epoch), tectonic shortening was calculated at 0.2 km in the southwest segment of the cross-section, 0.2 km in the central segment and 0.5 km for the northeast segment, for a total of 0.9 km. This represents a barely perceptible shortening over more than 200 km of the foldbelt.

In summary, the early Tertiary (pre-middle Eocene) shortening was by far the most important, affecting the southwest and central segments about equally. The mid-Tertiary (late Eocene to late Oligocene) shortening was much less important, but affected mainly the central segment of the cross-section. Finally, the late Tertiary (Miocene) shortening was substantially less again, but was concentrated in the most distal, northeastern segment of the cross-section.

Location Map for Cross-Section



(modified from Lane and Dietrich, 1995)

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