THE CENOZOIC STRUCTURAL EVOLUTION OF THE NORTHEASTERN BROOKS RANGE, ALASKA

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ABSTRACT

The northeastern Brooks Range is an active Cenozoic fold-and-thrust belt in northeastern Alaska. The regional structure of the range is dominated by basement-cored anticlinoria that each reflect one or more horses in a regional north-vergent duplex between a floor thrust at depth and a roof thrust near the base of the overlying sedimentary cover sequence. Although first-order regional structures are controlled by the location of these basement horses, the overlying sedimentary cover sequence generally is detached and has deformed independently of the underlying basement. Variations in the style of deformation within both the basement and sedimentary cover are governed by a number of different factors, including the composition of the basement, the character of the regional detachment horizon near the base of the sedimentary cover sequence, and the amount of regional shortening.

Apatite fission-track studies document four periods of unroofing in the northeastern Brooks Range: ~60 Ma in the south, 45 to 40 and 35 to 28 Ma in the central and northern part of the range, and ~25 Ma along the range front. Areal distribution of these ages implies that the fold-and-thrust belt generally grew from south to north, with considerable apparent out-of-sequence thrusting and variation in the age of individual structures along strike.

INTRODUCTION

The northeastern Brooks Range is part of the Cordilleran foreland fold-and-thrust belt and is one of the youngest fold-and-thrust belts in the circum-Arctic region. This part of the Cordillera is unusual in that it is actively prograding seaward across a rifted continental margin and not towards a continental interior (Fig.1). The oldest "basement" rocks involved in this thrusting are not cratonic crystalline rocks but slightly metamorphosed sedimentary and volcanic rocks. The structural evolution of this region provides new clues to the sequential development of foreland fold-and-thrust belts as well as important information on one of the few unexplored areas remaining in onshore North America.

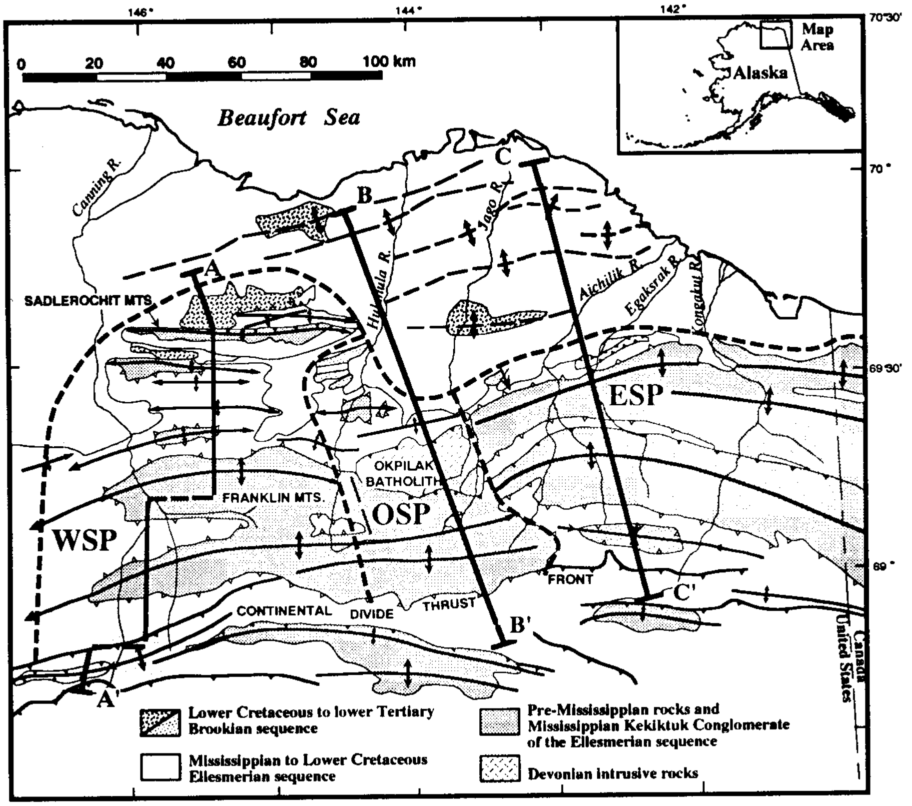

Fig.1. Generalized tectonic map of the northeastern Brooks Range showing the structural provinces and locations of balanced cross-sections (modified from Wallace and Hanks, 1990). Solid teeth on thrust faults indicate older-over-younger thrust faults that duplicate stratigraphic section; open teeth indicate detachment surfaces along which there has been slip but no duplication of stratigraphic section. Lines A-A', B-B', and C-C' are the locations of balanced cross sections shown in Fig.3. WSP = western structural province; OSP = Okpilak batholith structural province; ESP = eastern structural province.

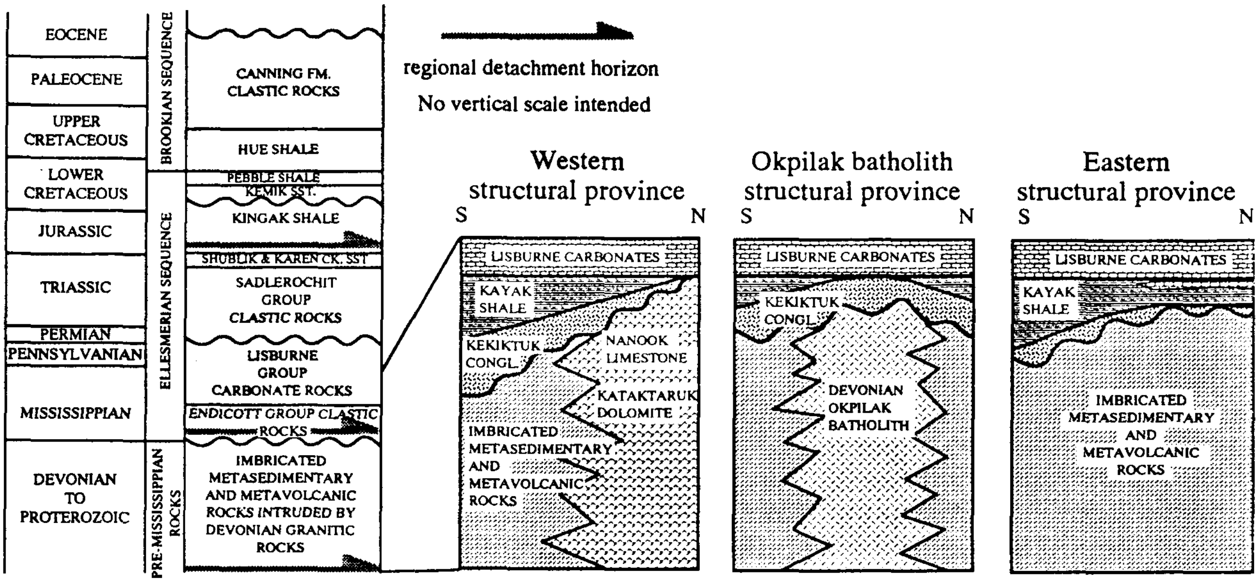

Fig.2. Simplified stratigraphy of the northeastern Brooks Range illustrating the regional stratigraphic variations in the basal conglomerate of the Ellesmerian sequence and the overlying shale in which the regional roof thrust is localized.

In this paper, we summarize the structural evolution of this Cenozoic fold-and-thrust belt with particular emphasis on how the stratigraphy has influenced regional variations in structural style. Apatite fission-track cooling ages from throughout the range provide clues as to how the range grew through time.

REGIONAL GEOLOGIC SETTING

The majority of the shortening within the main axis of the Brooks Range is Mesozoic in age (Mull, 1982; Mayfield et al., 1983; Moore et al., 1992). In contrast, the northeastern Brooks Range, a northern salient of the Brooks Range, originated in Cenozoic time, with deformation continuing today (see Wallace and Hanks, 1990, for summary). This young fold-and-thrust belt structurally elevates and juxtaposes some of the oldest rocks of the Brooks Range with much younger rocks deposited in the adjacent foredeep (Fig.1). The basement rocks are Proterozoic to lower Paleozoic, slightly metamorphosed and multiply-deformed sedimentary and volcanic rocks of basinal affinity similar to Proterozoic and lower Paleozoic rocks in both the main axis of the Brooks Range to the west and the Canadian Cordillera to the east (Reiser et al., 1971, 1980; Lane, 1991; Moore et al., 1992). These rocks are overlain by carbonate and clastic rocks of the Mississippian to Cretaceous Ellesmerian sequence (Fig.2), which were deposited on a south-facing passive continental margin (Mull, 1982; Mayfield et al., 1983; Moore et al., 1992). In contrast, the overlying Cretaceous and younger clastic rocks of the Brookian sequence (Fig.2) were deposited in a foredeep related to the growing Brooks Range to the south (Mull, 1985; Molenaar et al., 1987).

REGIONAL STRUCTURAL STYLE

The regional structural style of the northeastern Brooks Range is dominated by broad, generally east-trending anticlinoria. Pre-Mississippian rocks are exposed in the cores of these folds, with Ellesmerian sequence rocks defining their limbs. The anticlinoria are interpreted to reflect horses within a north-vergent duplex bounded by a floor thrust at depth in the pre-Mississippian rocks and a roof thrust near the base of the overlying cover sequence (Fig.3; Wallace and Hanks, 1990). Regional variations in the lithology and structure of the basement rocks, the thickness and lithology of the interval in which the roof thrust has been localized, and the amount of shortening have resulted in regional variations in the structural style of both the basement and the cover sequence (Hanks et al., 1991). As a result, the northeastern Brooks Range can be further subdivided into three structural provinces (Fig.1; Wallace and Hanks, 1990): the western structural province, the eastern structural province, and the Okpilak batholith structural province.

In the western structural province, widely spaced anticlinoria (Fig.1) are interpreted to reflect widely spaced and nonoverlapping horses within the Cenozoic regional basement duplex. The wide spacing of the horses probably is due to the relatively low regional shortening (~27%, Fig.3A; Wallace, 1993). In general, the pre-Mississippian rocks have deformed as relatively competent slabs in the regional duplex, with little shortening accommodated by penetrative structures (Fig.3A; Ziegler, 1989; Hanks and Wallace, 1992). Consequently, the Ellesmerian sequence rocks overlying the roof thrust also have shortened by the same amount as in the underlying duplex (i.e., ~27%). Additional

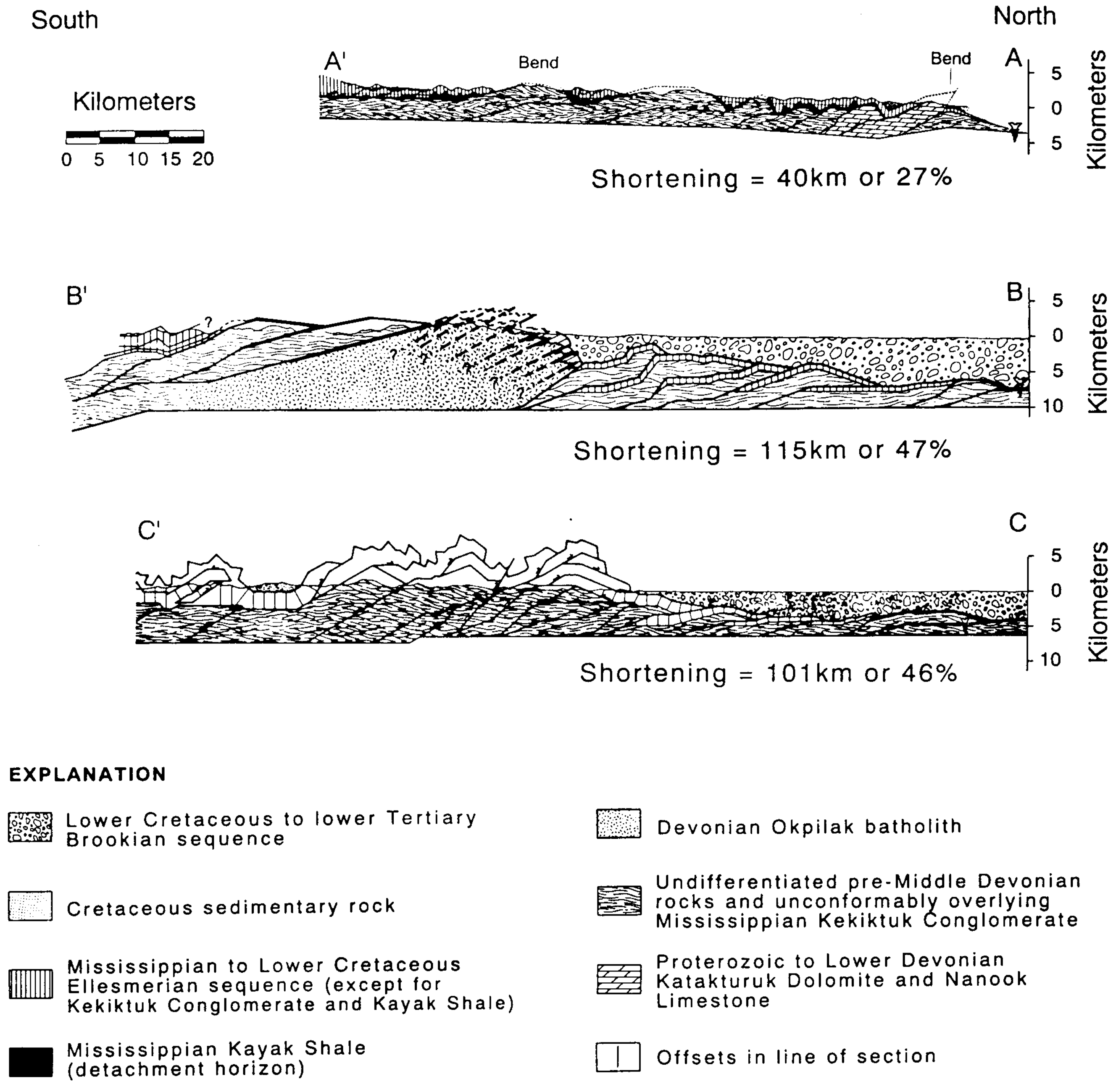

Fig.3. A-C. Three regional balanced cross-sections across the northeastern Brooks Range. A-A': Canning River transect, western structural province (from Wallace, 1993); B-B': Okpilak batholith transect, Okpilak batholith structural province (from Hanks and Wallace, 1990); C-C': Aichilik River transect, eastern structural province (from Hanks, 1993). All three sections were line balanced using the top of the basement as datum. In the WSP, the base of the Lisburne limestone also was line balanced. In the OSP, the batholith was area balanced.

shortening, not shown on Fig.3A, probably has occurred above a deeper detachment.

In most of the province, the cover sequence is separated from the underlying pre-Mississippian sequence by the roof thrust of the regional duplex, which is localized in a thick shale horizon near the base of the cover sequence (Fig.2). This shale horizon, the Mississippian Kayak Shale, has served as a very effective décollement horizon throughout most of the province, permitting the overlying carbonate and clastic rocks to accommodate the shortening of the underlying duplex, but with a different structural style. This deformation has been primarily by detachment folding with few thrust faults (Fig.3A). However, in the Sadlerochit

Mountains in the northern part of the province, the Kayak Shale is depositionally thin or absent (Figs.2 and 3). Here, the cover sequence has remained structurally coupled to the underlying basement rocks and has deformed with them as a competent thrust sheet (Fig.3A).

In contrast, the eastern structural province is characterized by only two broad and arcuate anticlinoria (Fig.1). This geometry is interpreted to reflect two anticlinal stacks within the Cenozoic basement duplex, with individual horses smaller and more closely spaced than to the west (Fig.3C; Hanks, 1993). This change in structural style from the western structural province probably reflects an increase in the amount of regional shortening (~46%, Fig.3C; Hanks, 1993). As in the west, the basement rocks probably deformed relatively competently, with the majority of the slip transmitted into the overlying Ellesmerian sequence.

In the eastern structural province, the Ellesmerian sequence above the Kayak Shale has deformed by both thrust faulting and detachment folding in order to accommodate the regional shortening of the underlying basement duplex (Fig.3C; Hanks, 1993). The increase in Cenozoic thrust faulting within the cover sequence as compared to the western structural province is in part due to the increased amount of regional shortening in the east. In addition, significant changes in the lithology and thickness of the Kayak Shale could contribute to this change in structural style. The Kayak Shale is thick and predominantly shale in the southern part of the eastern province, but becomes progressively siltier towards the north, with the development of significant carbonate horizons towards the range-front region (Fig.2; Hanks, 1993). This change in lithology probably decreased the effectiveness of the Kayak Shale as a detachment horizon, resulting in more thrust faults ramping upsection.

In the intervening Okpilak batholith structural province, the pre-Mississippian sequence was intruded by a large Devonian granitic batholith (Figs.2 and 3). During Cenozoic thrusting, the batholith initially may have behaved as a structural buttress, but eventually was incorporated as a horse within the regional basement duplex and displaced northward above the floor thrust (Fig.3B; Hanks and Wallace, 1990). Before and during displacement, the batholith deformed internally, primarily by formation of penetrative fabrics and associated semiductile shear zones and small-scale thrust faults. The Mississippian Kayak Shale is depositionally thin to absent in the vicinity of the batholith (Fig.2; Sable, 1977). Consequently, during Cenozoic deformation the Ellesmerian sequence remained structurally coupled to the underlying batholith and also was deformed penetratively and by small-scale thrust faults and related folds. Where the pre-Mississippian rocks are stratified metasedimentary and metavolcanic rocks north and south of the batholith, the basement and cover rocks deformed in a structural style similar to that seen to the east and west (Fig.3). Shortening across the entire Okpilak batholith province is estimated to be ≤47 percent (Hanks and Wallace, 1990).

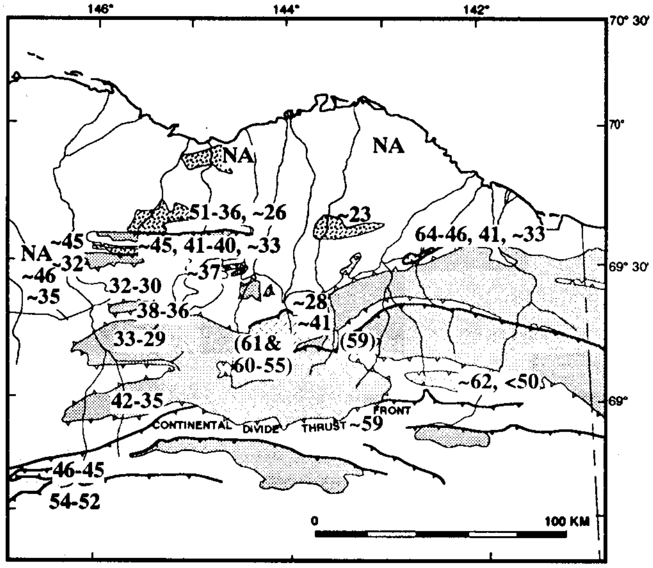

Fig.4. Simplified tectonic map of the northeastern Brooks Range showing the location of apatite fission-track cooling ages. Ages in parentheses are other isotope cooling ages. NA represents fission-track samples that have not been annealed.

TIMING OF CENOZOIC DEFORMATION

Apatite fission-track cooling ages from detrital apatites in the pre-Mississippian and younger clastic rocks, and primary apatites from the Okpilak batholith can be interpreted to reflect uplift and unroofing of individual anticlinoria and consequent cooling of apatite due to displacement on the underlying thrust faults (O'Sullivan et al., 1993). Apatite cooling ages from the entire range (Fig.4), and the available U/Pb, K/Ar, and $^{40}Ar/^{39}Ar$ data from the Okpilak batholith and related Devonian intrusions define different regional patterns of cooling during four time periods: 61 to 44 Ma, 42 to 35 Ma, 33 to 28 Ma and 26 to 23 Ma. The ages are interpreted to reflect times of rapid cooling, so these time periods probably coincide approximately with regional deformational episodes. Similar episodes of tectonic activity are reflected by syntectonic Tertiary deposits of the Canadian Beaufort Sea (Dietrich and Lane, 1992).

The regional distribution of apatite cooling ages indicates that there are significant regional complexities in the uplift and unroofing history of the belt, suggesting that the northeastern Brooks Range fold-and-thrust belt did not grow in a simple and continuous forward-propagating fashion (Figs.4 and 5). To the contrary, deformation was episodic, with significant apparent out-

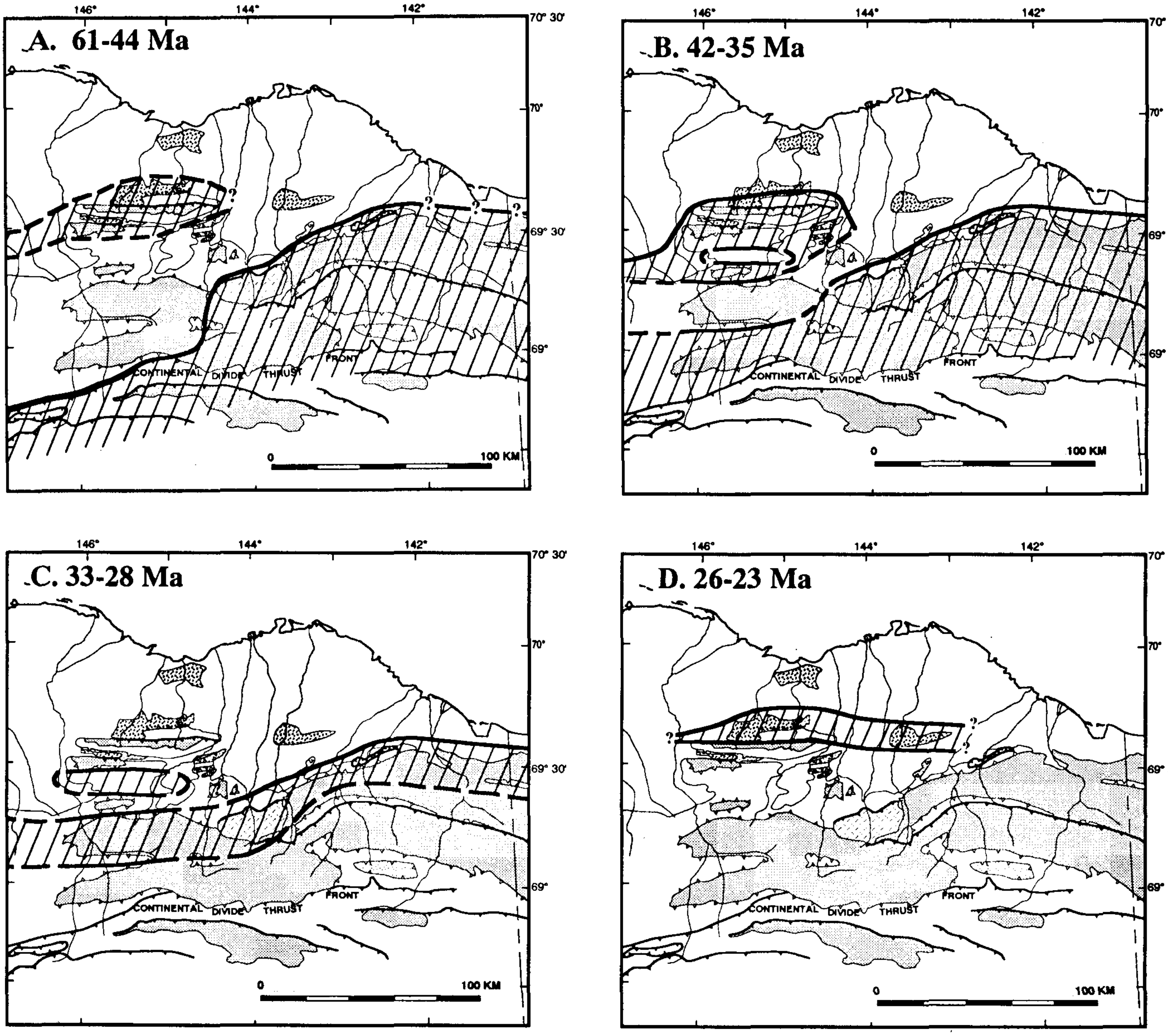

Fig.5. A-D. Simplified tectonic maps showing sequential structural development of the northeastern Brooks Range based on apatite fission-track cooling ages and other isotopic cooling ages. Shading represents areas where apatite ages are interpreted to reflect uplift due to deformation.

of-sequence thrusting as well as variations in the age of individual structures along strike.

Basement rocks in the eastern structural province and the southern part of both the Okpilak and western structural provinces were first cooled 61 to 44 Ma (Fig.5A). Other dates from the Devonian granitic rocks in the Okpilak batholith structural province, including a U/Pb lower concordia intercept (Dillon et al., 1987) and $^{40}Ar/^{39}Ar$ on white mica (P. Layer, pers. commun., 1993), suggest cooling of the granitic rocks through a higher blocking temperature at about this time (~60-55 Ma; Fig.4). Cooling of Cretaceous and younger foredeep deposits also occurred in the northwest (Figs.4 and 5A).

The majority of shortening within the regional basement duplex probably occurred between 42 and 35 Ma. Apatite ages from rocks throughout the range suggest cooling during this time, with deformation occurring locally as far north as the Sadlerochit Mountains (Fig.5B). Subsequent uplift between 33 and 28 Ma probably was limited to the range-front region in the eastern and Okpilak batholith provinces and the anticlinorium along strike, but far from the range front in the western province (Fig.5C). During this time interval, there was no significant uplift north of the Sadlerochit Mountains. Cooling between 26 and 23 Ma occurred in the area north of the range-front fault of the Sadlerochit Mountains (Fig.5D) and may have been due to the activation of a deeper detachment level and related uplift of the entire region.

SUMMARY AND CONCLUSIONS

The northeastern Brooks Range of northern Alaska is a Cenozoic fold-and-thrust belt involving Proterozoic through Cenozoic rocks. The Proterozoic to lower Paleozoic polydeformed basement has been deformed in a Cenozoic-age, north-vergent, regional-scale duplex between a floor thrust at depth and a roof thrust near the base of the overlying Mississippian and younger cover sequence. In general, the cover sequence has deformed independently of the underlying basement rocks above this regional roof thrust. However, in those areas where the detachment horizon containing the roof thrust is depositionally thin or absent, the cover sequence has remained structurally coupled to the underlying basement rocks and shares with them their Cenozoic structural style.

Apatite fission-track cooling ages and other geochronologic data suggest that most of the thrusting and related uplift of the range occurred prior to 33 Ma. However, shortening and related uplift did not progress smoothly from south to north or occur synchronously along strike. Thrusting began earlier and with greater amounts of uplift in the south and east, with several thrust faults probably active at any one time during initial growth of the belt. Hindward thrust faults probably were reactivated after their initial formation in order to accommodate thickening and steepening of the orogenic wedge as thrusting proceeded toward the foreland. Large, laterally continuous structures did not necessarily form during a single period of deformation or synchronously along strike.

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