APATITE FISSION-TRACK EVIDENCE OF EPISODIC EARLY CRETACEOUS TO LATE TERTIARY COOLING AND UPLIFT EVENTS, CENTRAL BROOKS RANGE, ALASKA

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ABSTRACT

Apatite fission-track (AFT) data trends suggest that episodic late Mesozoic and Cenozoic cooling events recorded in the central Brooks Range were a consequence of accelerated uplift and erosion. For AFT studies, cooling from >120 °C to <50 °C over times of 1-10 Ma results in predictable AFT data trends. This paper summarizes AFT results from six areas forming a north-to-south transect through the central Brooks Range: the Endicott Mountains allochthon near Atigun Pass (n=16), Killik River (n=8), Doonerak (n=6), and three orthogneiss bodies --Chandalar (n=14), Arrigetch (n=6), and Igikpak (n=12).

The AFT data from the Atigun Pass and Killik River areas show two cooling events, at ~100±5 Ma (Albian) and at ~60±4 Ma (Paleocene). The youngest AFT data, from the Doonerak antiform, suggest cooling there at ~24±4 Ma (late Oligocene). Data from the Chandalar orthogneiss bodies suggest two phases of cooling, at ~65 Ma (Paleocene) and between ~40-20 Ma (late Eocene to late Oligocene). The western tip of Arrigetch pluton and the main (western) Igikpak pluton cooled at ~39±2 Ma (late Eocene). In contrast, the eastern part of Igikpak pluton and the main (eastern) part of Arrigetch pluton cooled later at ~23±4 Ma (late Oligocene).

In summary, the AFT data from the central Brooks Range show evidence of cooling episodes at ~100, ~60, ~40, and ~25 Ma. Uplift, erosion, and subsequent cooling were consequences of changing tectonic regimes; however, speculation on such regimes is beyond the scope of this paper.

INTRODUCTION AND METHODOLOGY

This paper presents preliminary results of a regional AFT thermochronology study aimed at interpreting the Cenozoic thermal history of the Brooks Range (Fig.1). Sixty-two samples were processed and analyzed using standard mineral-extraction, mounting, irradiation, and fission-track-counting methods (e.g., Naeser, 1979; Gleadow, 1984). Our principal aim here is to outline the fission-track evidence supporting the recurrence of Cenozoic uplift in an area that historically has been interpreted to have been tectonically inactive since latest Cretaceous-early Tertiary time (e.g., Mull, 1982).

Direct evidence of Tertiary deformation is missing from the Brooks Range because Upper Cretaceous and Tertiary strata largely have been eroded away and redeposited such that critical map relations are not preserved. In this paper, cooling events detected with fission-track data are inferred to have coincided with periods of uplift, accelerated erosion, and subsequent cooling. Because erosion mechanically has removed evidence of cooling events prior to ~100 Ma, this paper emphasizes times after ~100 Ma.

The estimated temperature range of apatite annealing used here, 50-120 °C and referred to as the partial annealing zone (PAZ), is a conservative estimate inferred from natural and laboratory annealing studies and thermal modeling (e.g., Naeser, 1979; Gleadow et al., 1983, 1986; Laslett et al., 1987; Green et al., 1989). The PAZ normally occurs at depths of 2-5 km in the earth's crust (assuming geothermal gradients of 20-30 °C). If cooling through the PAZ was rapid, the mean-age fission-track age of a profile of samples will approximate the time of cooling; otherwise, modeling is necessary to determine the meaning of the apparent age.

GEOLOGIC SETTING

Many geological summaries of the Brooks Range region exist in the literature (see Moore et al., 1992, and references therein), so only a brief outline is given here. From south to north, northern Alaska has three basic components: (1) the Yukon-Koyukuk province, consisting largely of mid-Cretaceous clastic rocks, which are underlain by obducted Devonian to Jurassic oceanic rocks along the basin margins, and by a Jurassic-Early Cretaceous island arc in the basin (Fig.1; Angayucham and Koyukuk terranes; terminology of Jones et al., 1987); (2) the Brooks Range, which consists of complexly faulted Paleozoic to upper Mesozoic continental margin assemblages and polymetamorphosed Precambrian to lower Paleozoic basement rocks (Arctic Alaska terrane); and (3) the North Slope subsurface, which consists of unmetamorphosed equivalents of the Paleozoic to upper Mesozoic strata exposed at the surface in the Brooks Range (also Arctic Alaska terrane).

The Brooks Range has long been considered to be a consequence of the Late Jurassic-Early Cretaceous Brookian orogeny (e.g., Mull, 1982). During this orogeny, the Arctic Alaska terrane was subducted beneath the already imbricated Angayucham and Koyukuk terranes (e.g., Patton and Box, 1989, and

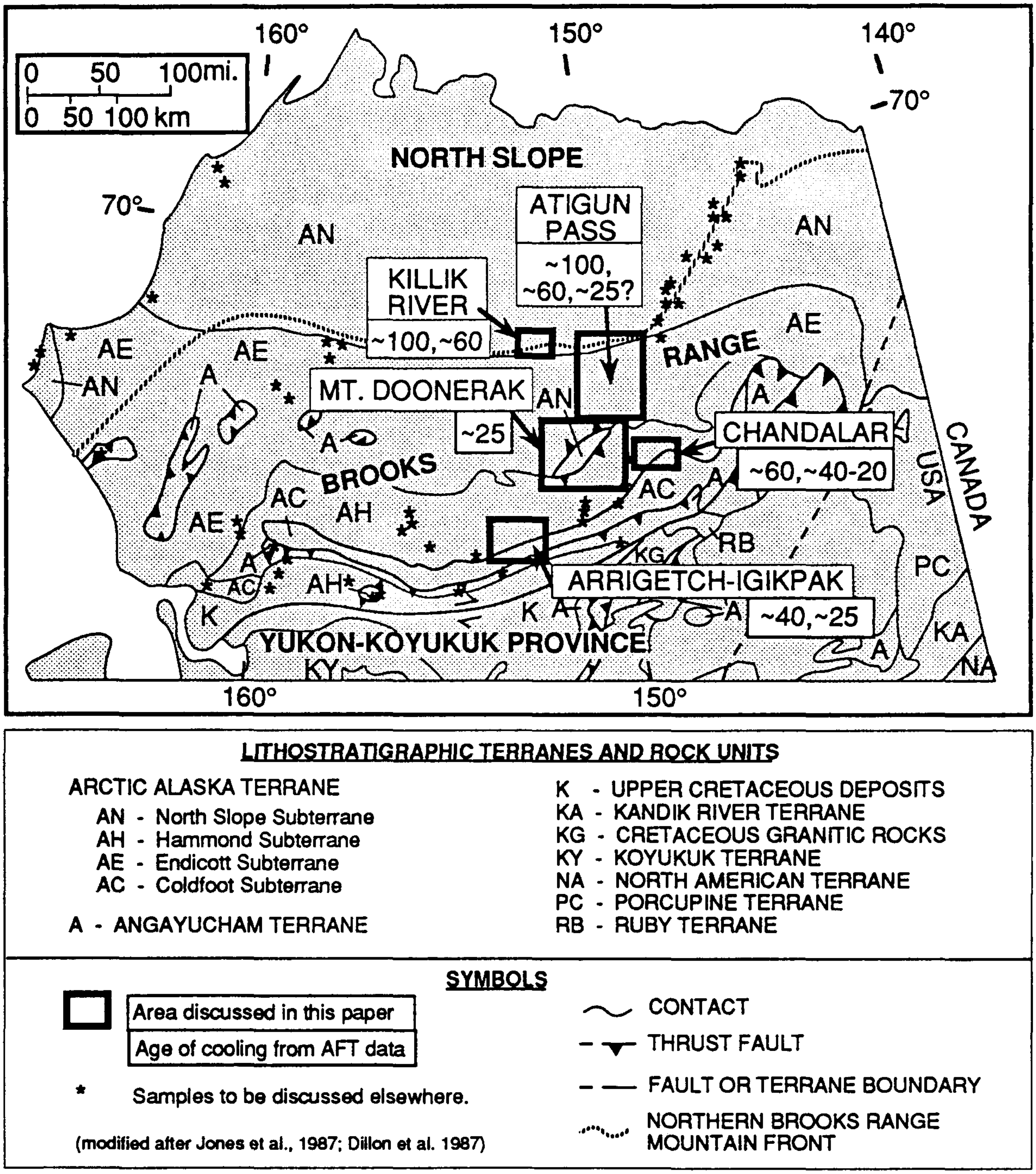

Fig.1. Generalized terrane map of northern Alaska showing the distribution of fission-track data collected during our regional study (stars) and areas discussed in this paper (labeled and outlined). The numbers beneath each label are the approximate times of cooling episodes (Ma). Evidence of older cooling episodes has been overprinted or eroded from areas where only young ages are preserved (i.e., Doonerak). For clarity, the vertical scale is slightly exaggerated.

references therein). The change of sediment-source area from the north (Franklinian and Ellesmerian sequences; Lerand, 1973) to the south (Brookian sequence) was a consequence of the Brookian orogeny (e.g., Mull, 1982; Molenaar, 1983; Bird, 1987). Various radiometric ages in the metamorphic core of the Brooks Range reflect Early Cretaceous cooling related to uplift (Turner et al., 1979; Dillon et al., 1987) but yield limited evidence of younger events.

In Late Cretaceous and early Cenozoic time, northward thrusting of the Brookian thrust front is suggested by folded strata of that age (Reiser et al., 1971; Kelley and Foland, 1987; Hubbard et al., 1987). Coeval detritus in basins of northeastern Alaska attest to reactivation of the Brooks Range source through time (Molenaar, 1983); however, most deformation episodes cannot be directly identified in the Brooks Range itself because Cenozoic strata largely have been eroded away. Where Cenozoic strata exist, there is abundant evidence of recurrent deformation, some of which is continuing today (Grantz et al., 1983; Carter et al., 1986). In northern Alaska, where suitable cross-cutting relations are missing, AFT studies routinely can identify cooling episodes that indirectly relate to deformation, uplift, and erosion episodes (e.g., O'Sullivan, 1993; O'Sullivan et al., 1993a,b; O'Sullivan and Murphy, 1992; Murphy et al., 1991, 1992).

RESULTS

Six areas in the central Brooks Range with suitable lithologies and significant vertical relief were selected for studying the timing of cooling events recorded by AFT data: (1) Doonerak antiform, (2) Atigun Pass to Atigun Gorge, (3) Killik River, (4) Chandalar orthogneiss bodies, (5) Arrigetch orthogneiss body, and (6) Igikpak orthogneiss body (Fig.1).

All sample locations, stratigraphic information, analytical results, discriminant plots, and interpretative details of samples are presented in O'Sullivan et al. (1993b). All ages reported herein are from AFT analyses, and all errors are ±2σ.

Doonerak Antiform

Five samples of Devonian and Triassic sandstone and pre-Mississippian volcanic rock were analyzed from the Doonerak antiform (Figs.1,2). Fission-track ages range between 33.9±16.0 and 22.0±4.0 Ma, mean track lengths between 14.6±0.2 and 13.1±0.5 μm, and standard deviations between 1.46 and 0.46 μm. All samples have long mean track lengths with narrow distributions indicating the tracks formed at low temperatures (<50 °C). Their weighted mean age of ~24±4 Ma is interpreted as the time of rapid cooling (Fig.2; O'Sullivan et al., in press).

Atigun Pass to Atigun Gorge

Twenty-four samples of Devonian conglomerate and sandstone of the Endicott Mountains allochthon were analyzed from Atigun Pass to Atigun Gorge (Fig.1). The AFT ages range between 102.3±11.4 and 63.9±14.2 Ma, mean track lengths between 14.7±0.4 and 12.1±0.6 μm, and standard deviations between 2.37 and 0.54 μm. In the samples from high elevations near Atigun Pass (~1,830 m), ages are ~100 Ma (weighted mean of 100.2±5.0 Ma), whereas at lower elevations and to the north (~850m), ages decrease to <65 Ma. For samples near Atigun Pass, mean lengths exceed 13.9 μm, length distributions are narrow, and standard deviations are small (<1.2 μm); all attest to rapid cooling (<50 °C). Samples from lower elevations have shorter mean lengths (<13.0 μm), broader length distributions, and larger standard deviations (>1.8 μm); all attest to longer residence in the PAZ.

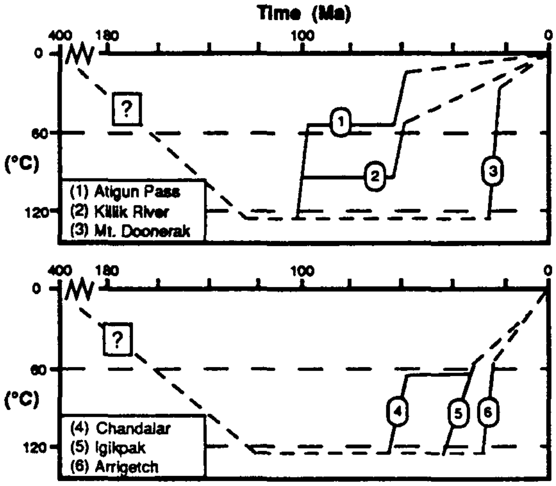

Fig.2. Summary of thermal histories for the areas discussed herein based on age data from 62 AFT samples (see O'Sullivan et al., 1993b). All AFT ages were reset to zero during the Brookian orogeny, when the temperature in all areas exceeded 120 °C (Harris et al., 1987; Dusel-Bacon et al., 1989). Dashed parts of curves represent times without temperature control (e.g., >120 °C and <50 °C).

There were two definite episodes of cooling (Figs.2,3). Samples near Atigun Pass cooled from >120 °C to <50 °C at about ~100±5 Ma. Lower elevation samples remained in the PAZ until after ~65 Ma. Based on zircon ages in the Atigun Pass area (Blythe et al., in press) and apatite ages from Atigun syncline, located just north of Atigun Gorge, the second cooling event occurred at ~60±4 Ma (O'Sullivan, 1993). A third cooling event after 40 Ma is suggested by bimodal age distributions for a young, low-elevation sample (interpreted by Murphy from data of Blythe et al., in press; i.e., Trevor Ck.). Data from Atigun syncline indicate that this event was at ~25±4 Ma (O'Sullivan, 1993).

Killik River

Eight samples of Devonian sandstone were analyzed from the Killik River area (Fig.1). The AFT ages from this area range between 75.6±8.8 and 63.6±6.6 Ma, mean track lengths between

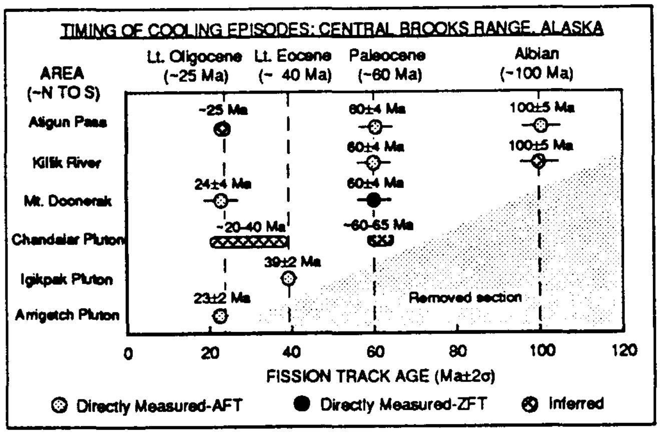

Fig.3. Summary plot of the approximate times of cooling episodes by area. The shaded field is eroded section. Trends are discussed in the text. The AFT age of cooling of ~25 Ma near Atigun Pass and the zircon fission track (ZFT) age from the Doonerak area are from Blythe et al. (in press). Ages are weighted means with ±2s errors. Only data from the main parts of Arrigetch and Igikpak plutons were used in calculating the reported times of cooling for those areas.

14.1±0.2 and 13.6±0.3 μm, and standard deviations between 1.43 and 1.07 μm. Many samples contain multiple single-grain age populations. Most single-grain ages range between ~55 and 65 Ma, but some exceed 90 Ma, suggesting only partial annealing.

Two episodes of cooling are interpreted for the Killik River area (Figs.2,3). After the apatite ages were totally reset at >120 °C, they cooled to ~80-90 °C before ~90 Ma (partially annealed older single grains represent the minimum time of cooling). Based on similar trends from Atigun Pass data, it is suggested that this cooling episode was at ~100±5 Ma. A second episode of rapid cooling in this area occurred between ~55 and 65 Ma (youngest, strongly annealed, single grains are maximum cooling ages). Similar data trends from Cobblestone Creek, located just to the north of the Killik River area, suggest that the second cooling event occurred at ~60±4 Ma (O'Sullivan, 1993).

Chandalar

Thirteen samples of Devonian orthogneiss were analyzed from the Chandalar orthogneiss bodies (hereafter pluton; Fig.1). Fission-track ages decrease downward over 1,000 m from 68.4±7.0 to 43±7.0 Ma, mean track lengths decrease from 14.7±0.5 to 12.6±0.3 μm, and standard deviations increase from 1.12 to 2.15 μm. These data indicate rapid initial cooling of samples from higher elevations at <65 Ma and later cooling of lower samples after ~45 Ma (Figs.2,3). Bimodal-age distributions in samples from intermediate elevations indicate their longer residence in a PAZ. Final cooling of samples from the lowest elevations was some time between ~40-20 Ma and is indicated by young single-grain ages, shorter mean track lengths, large standard deviations, and low numbers of long tracks (>15 μm).

Arrigetch-Igikpak

Fourteen samples of Devonian orthogneiss were analyzed from the Arrigetch and Igikpak orthogneiss bodies (Fig.1). Different results from the eastern and western parts of both bodies suggest that a high-angle fault crosscuts them. In the Arrigetch pluton, six fission-track ages decrease downward over 2,000 m from 45.4±16 to 21.3±3.4 Ma, mean lengths decrease from 13.0±0. to 12.3±0.7 μm, and standard deviations increase from 1.45 to 3.35 μm. Data from five samples from the main (eastern) body suggest rapid initial cooling at high elevations (23.1±1.1 Ma, weighted mean) and slower cooling below. A sixth sample, taken from the western tip of Arrigetch pluton, has an age of 45.4±16 Ma, a mean length of 13.29±3.0 μm, and a standard deviation of 3.35 μm, which is similar to the main (western) part of Igikpak pluton (below).

In the Igikpak pluton, three samples from the eastern end have fission-track ages that range from 27.1±11.6 to 24.3±2.4 Ma, mean lengths from 14.05±0.3 to 9.9±4.6 μm, and standard deviations from 0.97-3.24 μm. Their average age is 24.7±2.2 Ma (weighted mean), which is similar to the main part of Arrigetch pluton. Downward over 2,400 m of relief, eight samples from the main (western) part of Igikpak pluton have fission-track ages that decrease from 39.8±5.6 to 33.0±6.2 Ma, mean lengths that range from 14.14±0.6 to 12.24±0.8 μm, and standard deviations that range from 1.40 to 2.68 μm. Although the data are diffuse, the elevation-age distribution of the data suggests that cooling began by about 39.2±2.0 Ma (weighted mean, Figs.2,3).

These data suggest that either a fault or an abrupt thermal gradient separates the western and eastern parts of both orthogneiss bodies. A previously mapped fault occurs in the approximate position proposed here (Nelson and Grybeck, 1979), but the magnitude of offset has not been verified in the field.

SUMMARY

Beginning in the north, the data from the Atigun Pass, Killik River, and Doonerak antiform areas suggest that three episodes of regional cooling occurred along the north side of the central Brooks Range, during the Albian at ~100±5 Ma, during the Paleocene at ~60±4 Ma, and during the late Oligocene at ~24±4 Ma (Figs.2,3,4).

Data from the southcentral Brooks Range also show evidence of three cooling episodes (Figs.2,3,4).

Samples from higher elevations of the Chandalar pluton cooled initially during Paleocene times at ~60 Ma. Lower elevation samples either remained in the PAZ until ~40-20 Ma, or were mildly reheated (<95 °C) and then cooled again at ~25 Ma.

In the Arrigetch and Igikpak plutons, sample elevations overlap but fission-track ages do not, indicating that the eastern and western areas had different thermal histories. The main (western) part of the Igikpak body cooled during the late Eocene-early Oligocene at ~40 Ma, but its eastern part and the main (eastern) part of Arrigetch body cooled during the late Oligocene at ~25 Ma.

CONCLUSIONS

At least four cooling episodes, associated with uplift and erosion events on the order of 2-5 km, have occurred in the central Brooks Range since Early Cretaceous times (~100, ~60, ~40, ~25 Ma; Figs.2,3,4). Mechanisms for uplift, and of the tectonic regime in which they operated, are difficult to constrain and have not been considered here. Much work remains to be done toward resolving tectonic driving mechanisms in the Brooks Range, and fission-track thermochronology is contributing valuable new constraints.

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