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Discrepancies Between Geologic Evidence and Rotational Models—Talkeetna Mountains and Adjacent Areas of South-Central Alaska

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Abstract

Paleomagnetists have recently concluded that western and central Alaska underwent approximately 40° of counterclockwise rotation since early Tertiary time. The hinge zones of all mechanisms proposed so far to accomplish this rotation are located near or within the Talkeetna Mountains of south-central Alaska. Thus, the Talkeetna Mountains are in such a geographic location that if any of the proposed mechanisms did operate in the way postulated, the Talkeetnas should display structural features attributable to such a major crustal disturbance. Paradoxically, no such structural features were disclosed by geologic mapping. This contradiction should be resolved before any of the proposed mechanisms, or even the concept of differential rotation between various regions of Alaska, become widely accepted in attempts to decipher the tectonic history of southern Alaska.

INTRODUCTION

In recent years a number of paleomagnetic investigations on Cenozoic volcanogenic rocks from western and south-central Alaska, including the Talkeetna Mountains, have concluded that these parts of Alaska underwent an approximately 40° counterclockwise rotation within the last 50 m.y. (for instance, Coe and others, 1985, 1989; Panuska, 1987; Panuska and others, 1990; fig. 1). Three mechanisms have been proposed to accomplish the paleomagnetically suggested rotation: (1) oroclinal bending (for instance, Coe and others, 1985), (2) rotation caused by movements along curved strike-slip faults (Panuska, 1987), and (3) rotation by megakinking (Coe and others, 1989). The first two of the proposed mechanisms should have involved the shortening of large crustal segments between the rotating and the nonrotating, buttressing parts of Alaska. The amount of crust that should have been disposed of in order to make room for the rotating crustal blocks is quite large. Hence, in and near the zone of maximal crustal shortening, as in the Talkeetna Mountains, considerable numbers and types of compressional structures, directly attributable to such a major crustal shortening, should be present if the proposed mechanisms indeed have operated in the postulated way. In the case of the third proposed mechanism, that of megakinking, there should be at least one large pull-apart basin, with accompanying discontinuity between correlative rocks on either side of the basin, within and (or) near the hinge zone of the postulated megakink. Tensional faults would also be expected on both sides of such a pull-apart basin(s).

The areally extensive Talkeetna Mountains of south-central Alaska are located near and partly within the hinge zone of the proposed orocline and of the proposed megakinking structure. The Talkeetna Mountains also lie just south of a sharp bend in the surface trace of the Denali fault system. With such a critical geographic setting, the Talkeetna Mountains would be expected to display at least some geologic features resulting from an operation of the proposed mechanisms of oroclinal bending, strike-slip motions, or regional megakinking, or some combination of such activities.

A generalized geologic sketch map of the Talkeetna Mountains and adjacent central Alaska Range of south-central Alaska (after Csejtey and others, 1978, 1986, in press) is given in figure 2. The map shows the major rock units and all of the significant faults of the region. Much of the geology of the map area, and indeed that of south-central Alaska, is the result of the accretion of the Talkeetna superterrane to the ancient North American continent in about mid- and (or) Late Cretaceous time (for instance, Csejtey and others, 1982). For detailed lithologic descriptions and an interpretive overview of the geologic history of the map area, the reader is referred to the above-mentioned publications.

The overall lithologic character of Cenozoic sedimentary and volcanic rocks scattered throughout the Talkeetna Mountains indicates that in the Cenozoic the Talkeetna Mountains and adjacent central Alaska Range were never deeply buried, and hence that these regions in essence underwent only rigid-state (that is, brittle) deformation (Csejtey and others, 1978, 1986). Accordingly, the crustal shortening inherent in the proposed oroclinal bending and strike-slip mechanisms should be accomplished primarily by folding, thrust faulting, high-angle reverse faulting, and strike-slip faulting. The crustal extension inherent in the megakinking mechanism should be manifested by rotational pull-apart basins and by a swarm of extensional normal faults, trending roughly between north and northwest. This paper summarizes these rotational mechanisms in terms of their proposed structural consequences and lack of corresponding geologic features in the critically located Talkeetna Mountains region.

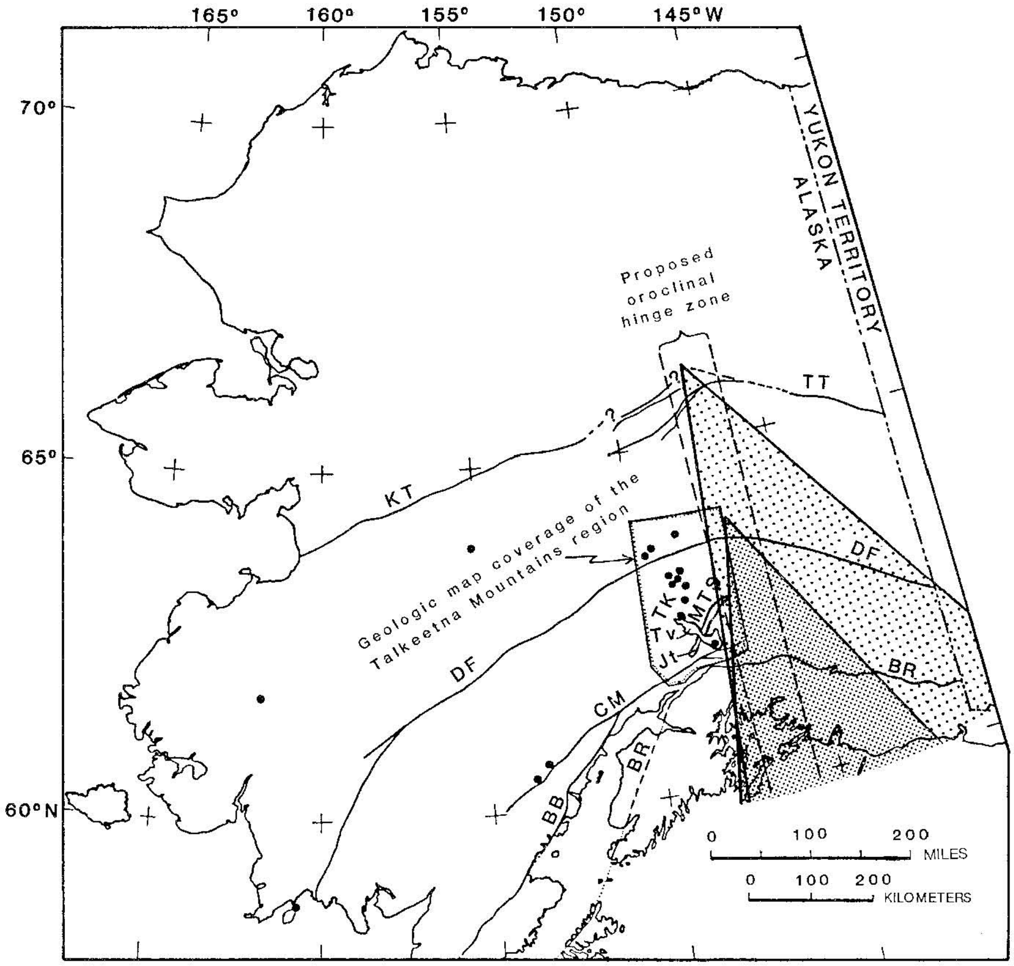


Figure 1. Locations of paleomagnetic study sites (large dots) that suggest approximately 40° of Cenozoic counterclockwise rotation for western and central Alaska. Map also shows approximate hinge zone of proposed Cenozoic oroclinal rotation and pie-shaped slices of excessive crust, discussed in text, if actual axis of rotation within hinge zone is located near Denali fault system (densely stippled area) or near Tintina fault (lightly stippled area). Map-unit symbols: Tv, exposure area of Tertiary volcanic rocks in Talkeetna Mountains; Jt, Late Jurassic trondhjemite pluton in Talkeetna Mountains. Other symbols used: TK MTS, Talkeetna Mountains; KT, Kaltag fault; TT, Tintina fault; DF, Denali fault system; CM, Castle Mountain fault; BB, Bruin Bay fault; BR, Border Ranges fault system. Faults dashed where approximate, dotted where covered, and queried where uncertain. Geologic map coverage of Talkeetna Mountains region by Csejtey and others (1978, 1986).

OROCLINAL BENDING

The oroclinal-bending hypothesis proposes that the north-trending hinge zone of the rotation of western and south-central Alaska is located in eastern Alaska near longitude 146° W., just east of the Talkeetna Mountains (Carey, 1958; Grantz, 1966; Coe and others, 1985). The implied approximately vertical rotational axis somewhere within this hinge zone (fig. 1) must thereby have formed the apex of a southward-widening crustal block that became successively narrower as oroclinal bending progressed. The implicit compression within the pie-shaped slice south of the axis would have to have occurred within and near the eastern Talkeetna Mountains (fig. 1). Tightening of such an orocline requires elimination of intervening crust, unless accommodated by global expansion (Carey, 1976), a controversial mechanism that even if operative and in keeping with extreme versions of expansion (Carey, 1976), could not have accommodated the amount of crust required. The width of the crustal wedge requiring elimination increases the farther north the rotational axis is located within the hinge zone (fig. 1). The paleomagnetic data and regional geologic considerations essentially require that the postulated rotational axis within the hinge zone be located at least as far north as the Denali fault system, but most probably the axis should have been located even farther to the north—that is, north of the postulated Kaltag-Tintina fault system. Thus, the amount of crust to be disposed of in front of the rotating Talkeetna Mountains, especially the southern Talkeetnas, is quite considerable. If a large mass of crust had been disposed of or displaced by this mechanism, one would expect to find major compressional features in this region. Strong evidence for the lack of such structural features is provided by a large and well-exposed northwest-trending outcrop area, about 80 km by 20 km in surface dimensions, of a more than 1,500-m-thick sequence of early to middle Cenozoic volcanogenic rocks in the southern and central parts of the Talkeetna Mountains (figs. 1, 2). The lower two-thirds of the volcanic sequence predates the proposed rotation, as shown by two paleomagnetic study sites (Hillhouse and others, 1985; Panuska and others, 1990), and should have been involved in the proposed rotation. Paradoxically, this volcanic sequence is essentially undeformed; its layering only varies from horizontal to subhorizontal, and intravolcanic regional unconformities are lacking. East of this volcanic sequence, and thus closer to the proposed hinge zone, detailed geologic mapping in the southeastern Talkeetna Mountains (Grantz, 1960a, b, 1961a, b, 1965) does not indicate the presence of significant compressional structural features. Still farther to the east, in the southern Copper River basin, and thus within the proposed hinge zone, available drill-hole correlation data and seismic-refraction profiles do not indicate, or even suggest, the presence of major compressional structural features (Alaska Geological Society, 1971a, b; Gary S. Fuis, U.S. Geological Survey, oral commun., 1989). The northwest-elongated exposure area of the Cenozoic volcanic rocks (Csejtey and others, 1978) and a Late Jurassic trondhjemite pluton (Csejtey and Nelson, 1979; figs. 1, 2), trending northeastward across the Talkeetna Mountains, preclude the presence of northeastward- or northwestward-trending strike-slip faults within the Talkeetna Mountains.

STRIKE-SLIP MECHANISM

The strike-slip mechanism hypothesis (Panuska, 1987) postulates that the rotation of western and south-central Alaska occurred as a result of right-lateral strike-slip offset in the Cenozoic along curved faults with small-circle geometries, such as the proposed Tintina-Kaltag fault system and the Denali fault system (Stout and Chase, 1980). According to this hypothesis, because the movements occur along curving strike-slip faults of uniform radii, the moving and (or) rotating blocks should undergo only insignificant internal deformation. However, neither the postulated Tintina-Kaltag fault system nor the Denali fault system is a strike-slip fault of small-circle geometry (Csejtey and others, 1982, 1986; Coe and others, 1989). The surface traces of both fault systems comprise long and straight segments separated by sharply curving and short segments (for instance, Beikman, 1980). Thus, the curvatures of both fault systems have nonuniform radii. Furthermore, the postulated Tintina-Kaltag fault system may not be a single fault system; its component Tintina and Kaltag faults may not join, but might each form a fault system independent of the other (W.W. Patton, Jr., U.S. Geological Survey, oral commun., 1989). Consequently, only the Denali fault system is discussed in this paper, but with the proviso that if the Tintina and Kaltag faults do form a single fault system, the general conclusions derived for the Denali system would also be applicable for the postulated Tintina-Kaltag system.

A sharp, southward-concave curvature occurs in the Denali fault system just north of the Talkeetna Mountains between two long and straight segments (Beikman, 1980; fig. 3). Assuming 200 km of dextral offset along the Denali system within the last 50 m.y. (after Nokleberg and others, 1985), the actively moving wide southern fault block, while passing the sharp curve, should rotate counterclockwise. This rotation should have resulted in a southward-widening, pie-shaped slice of excessive crust overlapping the eastern part of the Talkeetna Mountains. The central angle of the pie slice should be about the same as the angle of curvature of the Denali fault system, that is between 30° and 40°. The

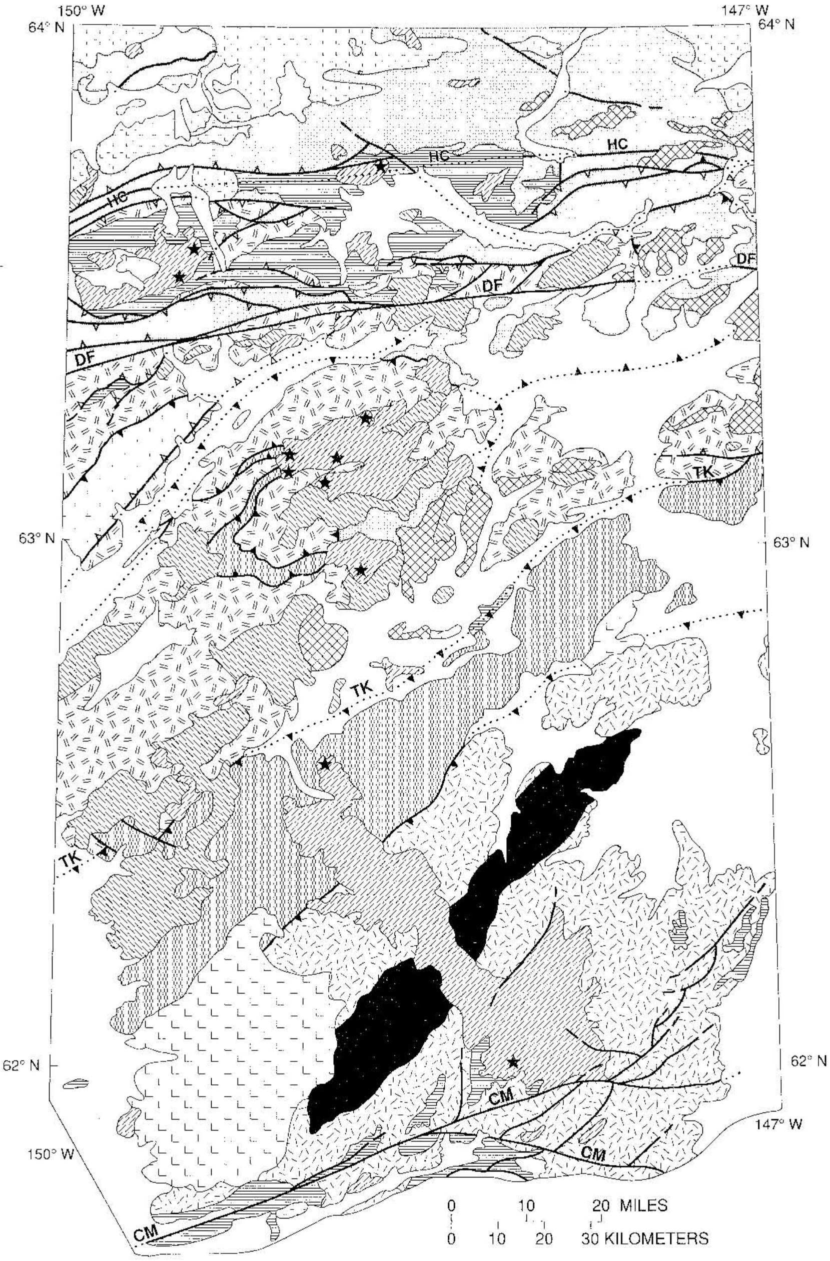


Figure 2. Generalized geologic map of Talkeetna Mountains and central Alaska Range of south-central Alaska (from Csejtey and others, 1978, 1986, in press).

structures resulting from this rotation should be most prevalent in the southeastern Talkeetna Mountains. As mentioned in conjunction with the oroclinal-bending mechanism, no such structures were mapped in that region. The counterclockwise rotation of such a moving fault block near the Talkeetna Mountains should have been accompanied by compensatory clockwise rotation within the block not far from, but west of, the Talkeetna Mountains. Without this compensatory clockwise rotation, a gap would have developed along the fault west of the Talkeetna Mountains, between the stationary northern block and the actively moving southern block. The most likely area for this compensatory rotation is the Talkeetna quadrangle, just west of the Talkeetna Mountains (fig. 3). However, compressional structures of the type expected from such rotation were not mapped in that region (Reed and Nelson, 1980). Moreover, such rotations within the moving fault block should be shown by time-progressive deformations of additional portions of the block. In other words, all portions of the moving fault block that already had passed the stationary curve in the fault should display at least some evidence for these rotational deformations. Again, no such evidence was found anywhere within the moving fault block west of the Talkeetna Mountains.

The lack of such rotational structures in the moving fault block is considered here to be supportive evidence for minimal movement along the Denali fault system in Cenozoic time (Csejtey and others, 1982, 1986, in press).

EXPLANATION

Surficial deposits (Quaternary)—Includes glacial ice

Terrestrial clastic sedimentary rocks (Pliocene to late Eocene)—In part, coal bearing

Postaccretionary subaerial and hypabyssal, felsic to mafic volcanic rocks (Miocene to Paleocene)

Epizonal granitic rocks (Oligocene to Paleocene)

Postaccretionary terrestrial clastic sedimentary rocks (Eocene to Paleocene)

Granitic rocks (early Tertiary and (or) Late Cretaceous)

Mesozonal and (or) epizonal granitic rocks and associated metamorphic rocks (Late and Early Cretaceous)

Preaccretionary and synaccretionary flysch and tectonic melanges (Cretaceous and Jurassic)

Sedimentary, volcanic, plutonic, and metamorphic rocks of the Peninsular terrane (Late Cretaceous to Early Jurassic)—Comprises part of Talkeetna superterrane

Trondhjemite pluton (Late Jurassic)—Part of the Peninsular terrane

Sedimentary and mafic volcanic rocks of the Wrangellia terrane (Late Triassic to Pennsylvanian)—Comprises part of Talkeetna superterrane

Allochthonous sedimentary and igneous rocks of the Chulitna district (Early Cretaceous to Late Devonian)

Metasedimentary and metaigneous rocks of the Yukon-Tanana and Nixon Fork terranes, undivided (Jurassic? to Precambrian?)—Both terranes are part of ancient North American continent

Contact—Approximately located

Fault—Dashed where inferred, dotted where concealed

Thrust fault—Dotted where concealed. Sawteeth on upper plate

High-angle reverse fault—Dashed where inferred, dotted where concealed. Sawteeth indicate upthrown side

★ Paleomagnetic study area—May include more than one study site

Note: TK, Talkeetna thrust fault; HC, Hines Creek fault; DF, McKinley fault of Denali fault system; CM, Castle Mountain-Caribou fault systems

Figure 2. Continued.

MEGAKINKING HYPOTHESIS

The megakinking hypothesis (Coe and others, 1989) explains the rotation of western and central Alaska in two steps. First, a set of elongate and parallel fault blocks are crosscut at a high angle into two segments. Then, individually but simultaneously, the fault blocks of one of the segments are pushed and rotated away from corresponding fault blocks in the other segment by northwesterly regional compressional forces (fig. 4). Applying the megakinking hypothesis to this part of Alaska, the hinge zone, where the set of elongate fault blocks have been cut into two segments, has been proposed to coincide roughly with longitude 148° W., which runs through the middle of the Talkeetna Mountains (fig. 5). The curved fault systems of Alaska, such as the Denali and the proposed Tintina-Kaltag system, are assumed to be part of the set of originally straight faults that outlined the elongate and parallel fault blocks. According to the megakinking hypothesis (Coe and others, 1989), large parts of the area of the Talkeetna Mountains should be underlain by at least one rotational pull-apart basin (figs. 4, 5). Geologic investigations to date in the Talkeetna Mountains and adjacent regions (Csejtey and others, 1978, 1986, in press) do not support this contention.

From the viewpoint of the geology of the Talkeetna Mountains, it would be more appropriate to locate the position of the hinge zone of the postulated megakink somewhere east of the Talkeetnas, perhaps across the

Copper River basin near longitude 146° W. In this case, the lack of known northeast-trending dextral strike-slip faults in the Talkeetna Mountains requires that the region between the Denali and Border Ranges fault systems be composed of one fault block. Consequently, the postulated rotational pull-apart basin should fully extend between the two fault systems, underlying a large part of the Copper River basin (fig. 5). The presence of such a northward-widening basin under the surficial deposits in the Copper River basin region is precluded by the wide and continuous belt of Paleozoic and Mesozoic rocks flanking the Copper River basin to the north (Beikman, 1980; Nokleberg and others, 1982; Warren J. Nokleberg, U.S. Geological Survey, oral commun., 1989), and in the basin itself by exploratory drill-hole data (Alaska Geological Society, 1971a, b), and by seismic-refraction profiles (Gary Fuis, U.S. Geological Survey, oral commun., 1989). Furthermore, if such a rotational pull-apart basin

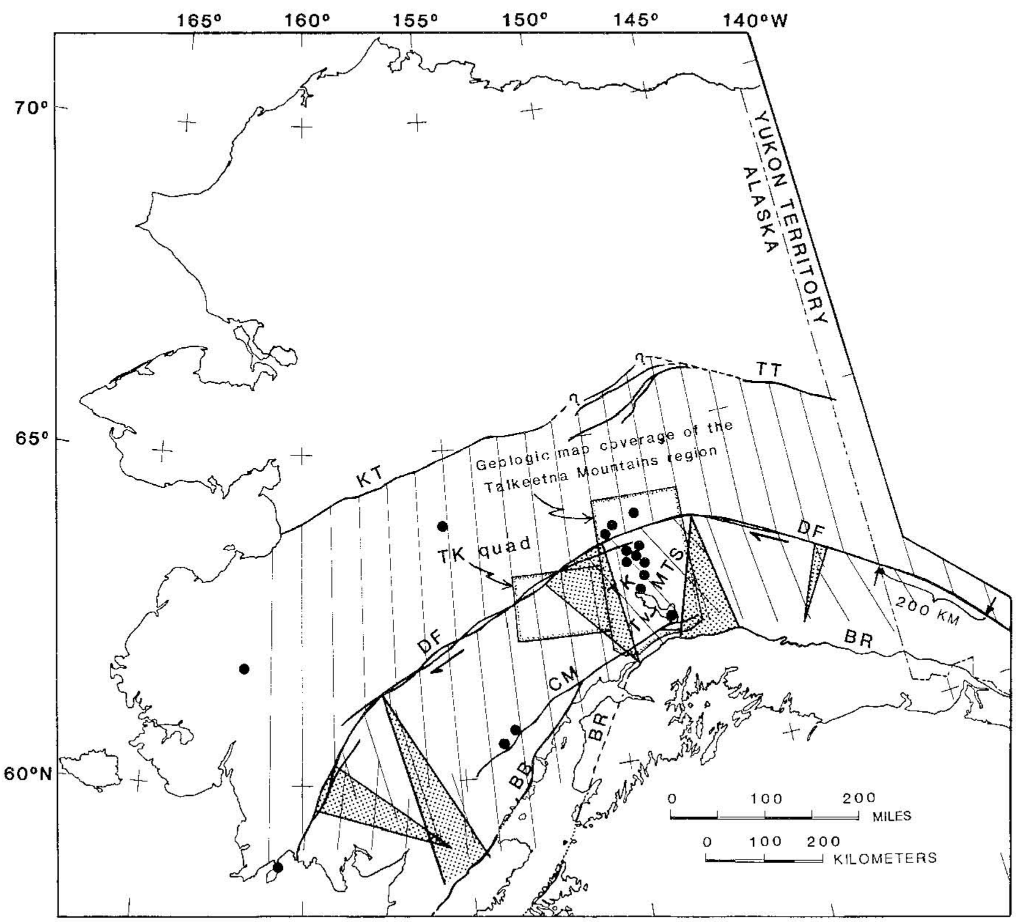


Figure 3. Relative rotational positions (black lines) and approximate locations and amounts of crustal shortening (stippled areas) due to counterclockwise and compensatory clockwise rotations within entire southern fault block of Denali fault system after 200 km of postulated Cenozoic movement of the block. Large dots indicate paleomagnetic study sites in western and south-central Alaska. Map-unit symbol: Tv, elongate exposure area of Tertiary volcanic rocks referred to in text. Other symbols used: TK quad, Talkeetna quadrangle; TK MTS, Talkeetna Mountains; KT, Kaltag fault; TT, Tintina fault; DF, Denali fault system; CM, Castle Mountain fault; BB, Bruin Bay fault; BR, Border Ranges fault system. Faults dashed where approximate, dotted where covered, and queried where uncertain. Geologic map coverage of Talkeetna Mountains region by Csejtey and others (1978, 1986).

did develop just east of the Talkeetna Mountains, then there also should be a number of roughly north- to northwestward-trending extensional faults in the Talkeetna Mountains. None are known to be present.

In addition to the foregoing discussion, it is important to point out that the schematic model of megakinking, as presented by Coe and others (1989) and reproduced in figure 4, is in fact geometrically incorrect. If rotation took place with each of the rotated fault slivers remaining connected to their nonrotated counterpart at their individual rotational axis, then at a 40°–50° rotation there should be gaps between the rotated fault slivers (fig. 6*A*). If one closes the gaps, and stacks the rotated fault slivers against the southernmost sliver, in response to the speculated northwesterly regional compression, then there should be left-lateral displacement along the fault that initially crosscut the original set of fault slivers (fig. 6*B*). In case of 45° rotation, the displacement of any point along this left-lateral fault or fault zone is a little over 7 percent of the original distance of that point from the rotational axis of the southernmost fault sliver. In case of 40° rotation, the displacement is nearly 10 percent.

Applying the above considerations to Alaska, it appears that if the megakinking mechanism did operate, then in addition to rotational pull-apart basins and related structures, there also should be a roughly north-south-trending, left-lateral fault or fault zone, or at least an S-shaped regional bend across southern and central Alaska somewhere near or between longitudes 146° W. and 148° W. Near the apex of the postulated Kaltag-Tintina fault system, left-lateral displacement along this hypothetical fault zone or regional bend should be about 45 km—that is, 7 percent of the approximately 640 km distance of the apex from the southern margin of continental Alaska. Near the apex of the Denali fault system, left-lateral offset should be about 23 km. Both distances are of sufficient magnitude to be disclosed even by 1:250,000-scale reconnaissance geologic mapping. No evidence for such left-lateral offsets was disclosed by reconnaissance geologic mapping near the Tintina and Kaltag faults (Chapman and others, 1971; Foster and others, 1983; Weber and others, 1978; Péwé and others, 1966) or along the apex of the Denali fault system (Csejtey and others, 1978, 1986, in press).

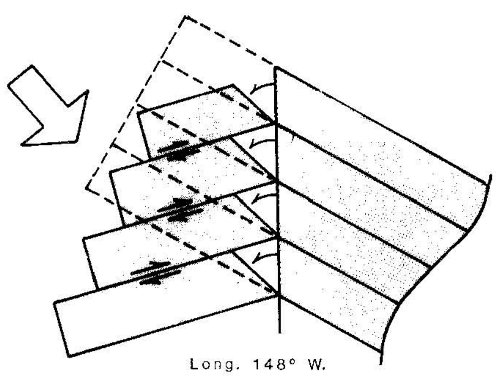


Figure 4. Schematic model of megakinking mechanism of Coe and others (1989). Model is geometrically incorrect because widths of rotated fault slivers should equal widths of nonrotated slivers. See figure 6*A* and text for discussion.

"DRAG" BETWEEN CONCURRENT STRIKE-SLIP FAULTS

Several U.S. Geological Survey colleagues (for instance, H.L. Foster, oral commun., 1989) discussed the possibility that the counterclockwise rotation of the Talkeetna Mountains region might be the result of concurrent dextral movements along the Denali fault system to the north and the Castle Mountain fault and (or) the Border Ranges fault system to the south. Accordingly, the Talkeetna Mountains region should be a tectonically independent block that is bounded by faults not only on the north and south, but on the east and west as well. However, eastern or western boundary faults were not observed in the field (Csejtey and others, 1978; Reed and Nelson, 1980). Furthermore, tectonic forces in south-central and southern Alaska, having been generated by generally northward plate motions during the Cenozoic, should have been strongest at the margin of the continent. Accordingly, dextral displacement along the Castle Mountain fault and (or) the Border Ranges fault system should have been concomitant with but greater than that along the Denali fault system. Thus, the resulting "drag" should have caused clockwise rotation in the Talkeetna Mountains.

CONCLUSIONS

The Talkeetna Mountains are critically located for testing the proposed Cenozoic counterclockwise rotations of western and south-central Alaska based on paleomagnetic data. Geological mapping of the Talkeetna Mountains, however, shows a lack of structural features required by such rotations and related movements. Thus, a contradiction exists between the geologic and paleomagnetic data. A resolution of these discrepancies is needed to assess the credibility of the proposed Cenozoic rotations between various regions of this part of Alaska, particularly before any of the various proposed mechanisms to explain such inferred rotations gains general acceptance in the deciphering of western and south-central Alaska's tectonic history.

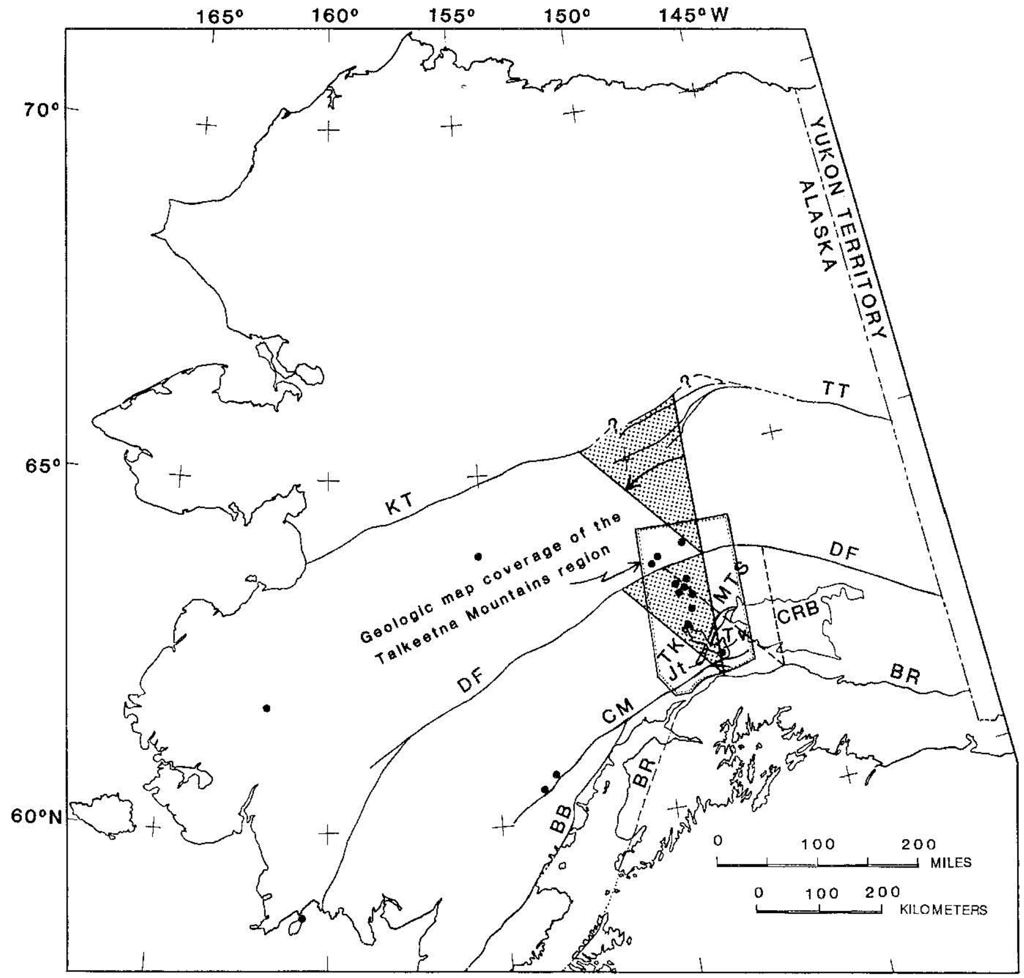
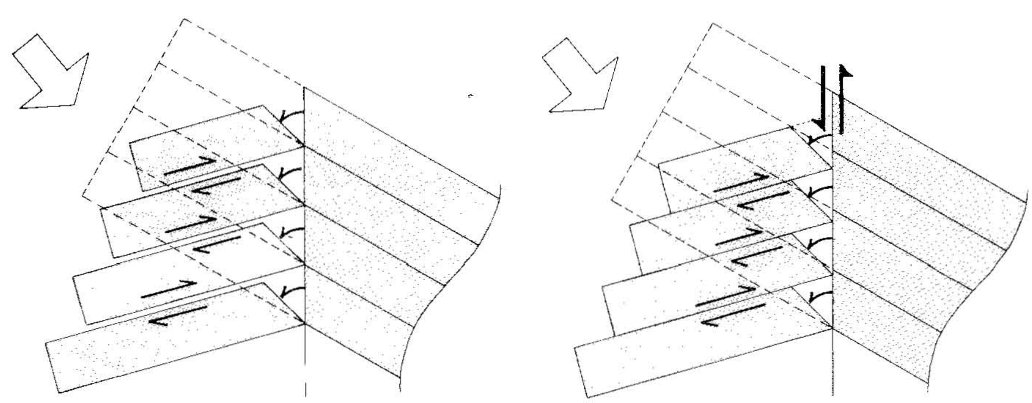


Figure 5. Approximate locations of rotational pull-apart basins in central Alaska from megakinking mechanism proposed by Coe and others (1989). Stippled triangular-shaped areas indicate locations of rotational pull-apart basins as originally postulated by Coe and his co-workers. Triangular area outlined by dashed lines between Denali and Border Ranges fault systems shows more likely location of at least one of rotational pull-apart basins in view of geology of Talkeetna Mountains. Large dots indicate locations of paleomagnetic studies. Map-unit symbols: Tv, elongate exposure area of Tertiary volcanic rocks discussed in text; Jt, Late Jurassic trondhjemite pluton discussed in text. Other symbols used: TK MTS, Talkeetna Mountains; CRB, Copper River basin; KT, Kaltag fault, TT, Tintina fault; DF, Denali fault system; CM, Castle Mountain fault; BB, Bruin Bay fault; BR, Border Ranges fault system. Faults dashed where approximate, dotted where covered, and queried where uncertain. Geologic map coverage of Talkeetna Mountains region by Csejtey and others (1978, 1986).



A *B*

Figure 6. Reconstructed model of megakinking mechanism of Coe and others (1989). *A*, With gaps between rotated fault slivers. *B*, With gaps closed and rotated fault slivers stacked against southernmost sliver. Note left-lateral offset along initial crosscutting fault.

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