DENALI FAULT SYSTEM OF SOUTHERN ALASKA: AN INTERIOR STRIKE-SLIP STRUCTURE RESPONDING TO DEXTRAL AND SINISTRAL SHEAR COUPLING

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Abstract. The Denali fault system (DFS) extends for ~1200 km, from southeast to south central Alaska. The DFS has been generally regarded as a right-lateral strike-slip fault, along which post late Mesozoic offsets of up to 400 km have been suggested. The offset history of the DFS is relatively unconstrained, particularly at its western end. For this study we calculated relative motion vectors at discrete points along the length of the DFS, based on the well-understood kinematic interaction between the North American, Pacific, and Kula plates, and the following assumptions: (1) The arcuate geometry of the DFS has existed essentially unchanged since the Late Cretaceous; (2) The Yukon-Tanana terrane and other terranes north of the DFS were fixed, in situ, prior to the accretion of the southern Alaskan terranes; and (3) Tangential and normal relative motion vector components calculated for points along the DFS using the plate model of Kelley [1993] describe the plate kinematics of the DFS since the Late Cretaceous. The consequent kinematic model for the DFS predicts that left-lateral stresses have acted upon the western end of the DFS for much of its history, and conflicting senses of shear exist between the eastern and western ends of the system. The offset history of the western end of the Denali fault system should be significantly different than the history of the central and eastern sections; consequently, individual crustal blocks in southeast and southwest Alaska may have undergone, respectively, clockwise and counterclockwise rotations. The sense of rotation predicted by our model is in agreement with rotations determined by paleomagnetic studies and provides an alternative model to the "Alaskan orocline" hypotheses.

INTRODUCTION

The Denali fault system (Figure 1) has long been recognized as a major crustal structure transecting much of Alaska. Sainsbury and Twenhofel [1954] and St. Armand [1954] simultaneously recognized the regional importance of faults identified by earlier workers. St. Armand [1957] postulated 250 km of right-lateral displacement and named the collective faults the Denali fault system (DFS). Since the recognition of the importance of the DFS to the tectonics of southern Alaska, it has been regarded as a right-lateral strike-slip fault of continental proportions [Grantz, 1966; Reed and Lanphere,

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1974; Lanphere, 1978; Stout and Chase, 1980]. Despite this consensus, the tectonic history of the DFS remains relatively unconstrained. Critical outcrops are rare, access is difficult, and to this day much of the region is incompletely mapped at detailed scales.

Grantz [1966] named or redefined six individual fault segments comprising the DFS. From west to east the segments are the Togiak/Tikchik fault, the Holitna fault, the Farewell fault, the Denali fault (subdivided into the McKinley and Hines Creek strands), the Shakwak fault, and the Dalton fault (Figure 1). At its western end, the DFS is mapped not as a single entity but rather appears to splay into a complex, poorly exposed set of crosscutting fault patterns [Beikman, 1980]. Somewhat more orderly on its eastern end, the DFS appears to join forces with the Chatham Strait fault. This structure in turn is truncated by the Fairweather fault [Beikman, 1980], the present-day North American plate Pacific plate boundary [Plafker et al., 1978]. Southeast Alaska (the "panhandle"), appears to be characterized by many subparallel, coast parallel faults and shear zones [Beikman, 1980], and could perhaps be considered a single megashear plate boundary.

Existing estimates of the sense of offset across each fault segment since the Late Cretaceous are dominantly right-lateral [Grantz, 1966; Stout et al., 1973; Forbes et al. 1973a; 1973b; 1974; Reed and Lanphere, 1974; Turner et al. 1974; Warhaftig et al., 1975; Eisbacher 1976; Hickman et al., 1977; 1990; Plafker et al., 1977; Lanphere, 1978, Stout and Chase, 1980]. However, the timing of offset and the total displacement across each individual fault segments are unclear, and controversial. For example, Csejtey et al. [1982] suggested that there are no lateral displacements across the McKinley strand of the Denali fault, while Jarrard [1986], Schultz and Aydin [1990], and Scholl et al. [1992] noted that in western Alaska sinistral slip is predicted from plate motion models.

The majority of structural studies on the DFS have been sited east of the Denali massif. Lanphere [1978 p. 817] stated that "the western section probably is the least known part of the fault system." Grantz [1966] proposed a right-lateral offset history for the Togiak/Tikchik, Holitna, and Farewell faults, and noted present-day scarps as high as 6 m. However, a clear record of right-lateral offsets for the western section has not yet been presented in the readily accessible literature. This paper explores the possibility that the DFS was not, and is not, a right-lateral strike-slip fault along all its entire length throughout its Cenozoic history. We present a kinematic model that suggests many areas of the western end of the DFS have experienced sinistral shear stress, and possibly even left-lateral offset, stemming from plate tectonic convergence and fault geometry. These stress fields may have caused the local counterclockwise rotation of small crustal blocks described in the paleomagnetic literature of western Alaska.

SHEAR STRESS AND BLOCK ROTATIONS

Rotation of crustal blocks along the obliquely convergent Pacific margin has long been recognized [Cox, 1957; Beck, 1976; Luyendyk et al., 1985; Wells and Coe, 1985]. Beck [1976, 1980, 1986] suggested that clockwise block rotations observed in the Pacific Northwest are related to right-lateral transform and obliquely subducting plate boundaries. Beck's schematic mechanism (Beck's Ball Bearings), shown in Figure 2, provides a readily understandable conceptual framework describing block rotation and translation at oblique margins.
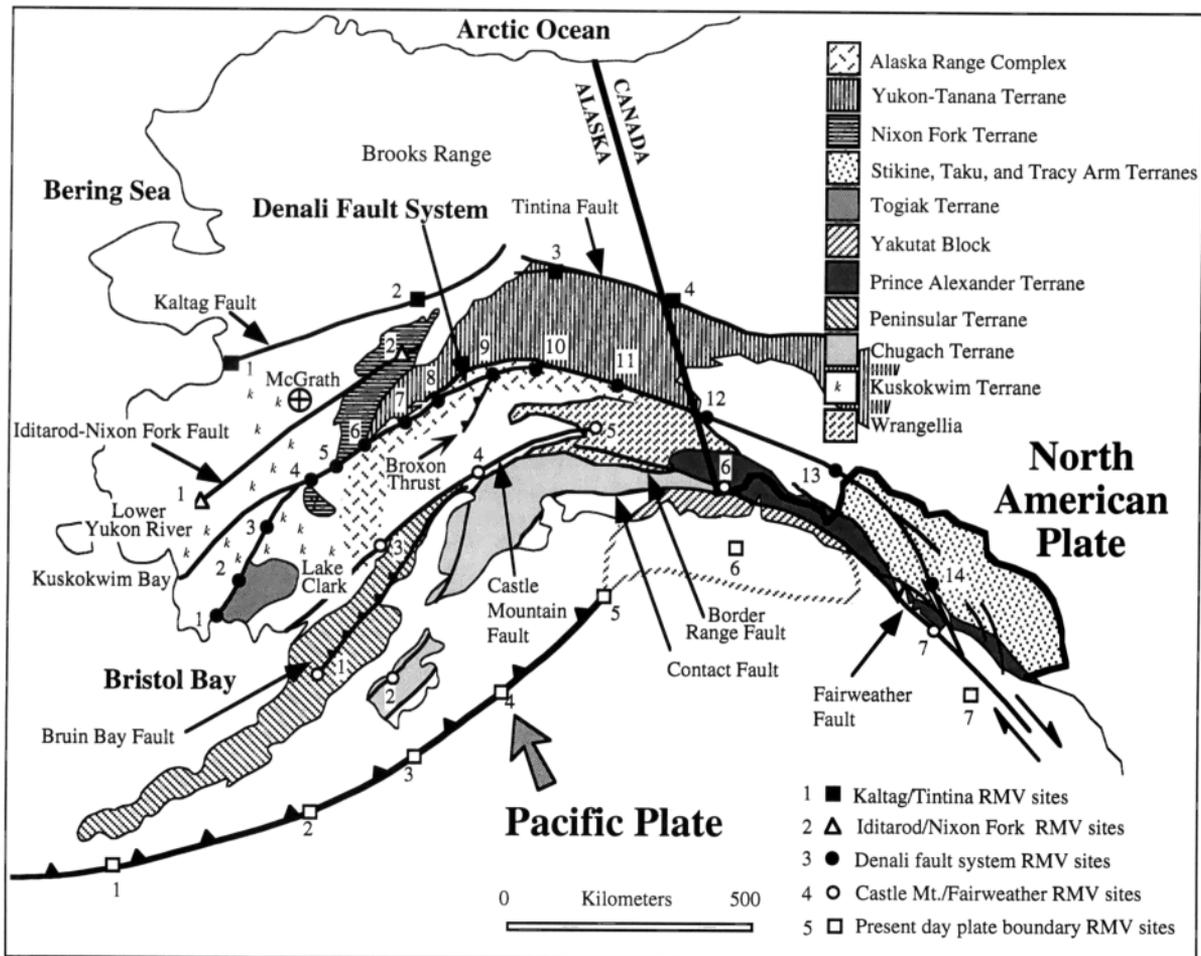
Fig. 1. Simplified, schematic terrane map of Alaska after Coe et. al. [1985] and Howell et al. [1985], showing the locations of major tectonostratigraphic terranes, structures, relative motion vector (RMV) analysis sites, and other localities mentioned in the text. Note that the Yakutat terrane extends offshore. RMV sites on the DFS are marked with a solid dot. Site 1 of the DFS is on the Togiak/Tikchik fault. Sites 2 and 3 of the DFS are on the Holitna fault. Sites 4-7 of the DFS are on the Farewell fault. Sites 8-10 of the DFS are on the McKinley strand of the Denali fault. Sites 11 and 12 of the DFS is on the Shakwak fault. Site 13 of the DFS is on the falton Fault. Site 14 of the DFS is on the Chatham Strait fault.

Though Beck's model is impractical on a crustal scale [McKenzie and Jackson, 1989] and was never intended to provide an accurate depiction of the rotation process (M. L. Beck, personal communication, 1993), empirical evidence of clockwise paleomagnetic rotations in regions characterized in the past by continental-scale right-lateral shear implies that a direct relationship between rotation and shear exists [Wells and Heller, 1988]. Experimental data concur: Cobbold et al. [1989] presented a sandbox experiment yielding counterclockwise rotations of up to 30° within a left lateral simple shear couple. The results of this experiment clearly suggests that complex deformation patterns should be expected within a shear couple, including right-lateral domino offsets.

Jarrard [1986] discussed strike-slip faulting at continental margins and concluded that obliquely subducting boundaries drive today's onshore strike-slip shear margins. Under oblique subduction, detached slivers of continental crust can be translated parallel to a convergent margin [Jarrard, 1986; Beck, 1983, 1989]. If actual transport is less than the maximum margin-parallel component of relative motion, the sliver will be subject to shear and could tend to fracture into rotating blocks [Beck, 1989]. Jarrard [1986] and Beck [1986] suggested that resistance to slip is at least partly a function of subduction zone age: Mature subduction zones offer less resistance to slip, while younger convergence zones generate greater resistance and corresponding block rotation.

Lewis et al. [1988] showed that in the Aleutian forearc accretionary prism, folding has occurred along axes perpendicular to plate convergence, followed by thrust faulting parallel to convergence, followed by strike-slip faulting. Right-lateral faults dominate west of a major transverse fault (at longitude 161°) while left-lateral faults are dominant to the east.

Pole of Rotation
Lat, Long, Omega

North
American
Plate
(Fixed)

Pacific Plate
(Moving)

(a)

Sinistral Strike Slip | Dextral Strike Slip

North
American
Plate
(Fixed)

Pacific Plate
(Moving)

(b)

5.6 Ma: Dextral regime switches to sinistral regime. Crustal block beneath Denali (Mt. McKinley) begins to respond to shear couple by anticlockwise rotation. Uplift of Denali begins (Fitzgerald et al., 1993) causing glacial excavation.

3.0 Ma: Continued sinistral shear couple causes additional anticlockwise rotation. Maintaining its drainage channel, the Muldrow glacier flows to the right.

0 Ma: Denali reaches 6 km elevation. Anticlockwise rotation of the crustal block under a sinistral regime has created a right-lateral offset of the Muldrow Glacier.
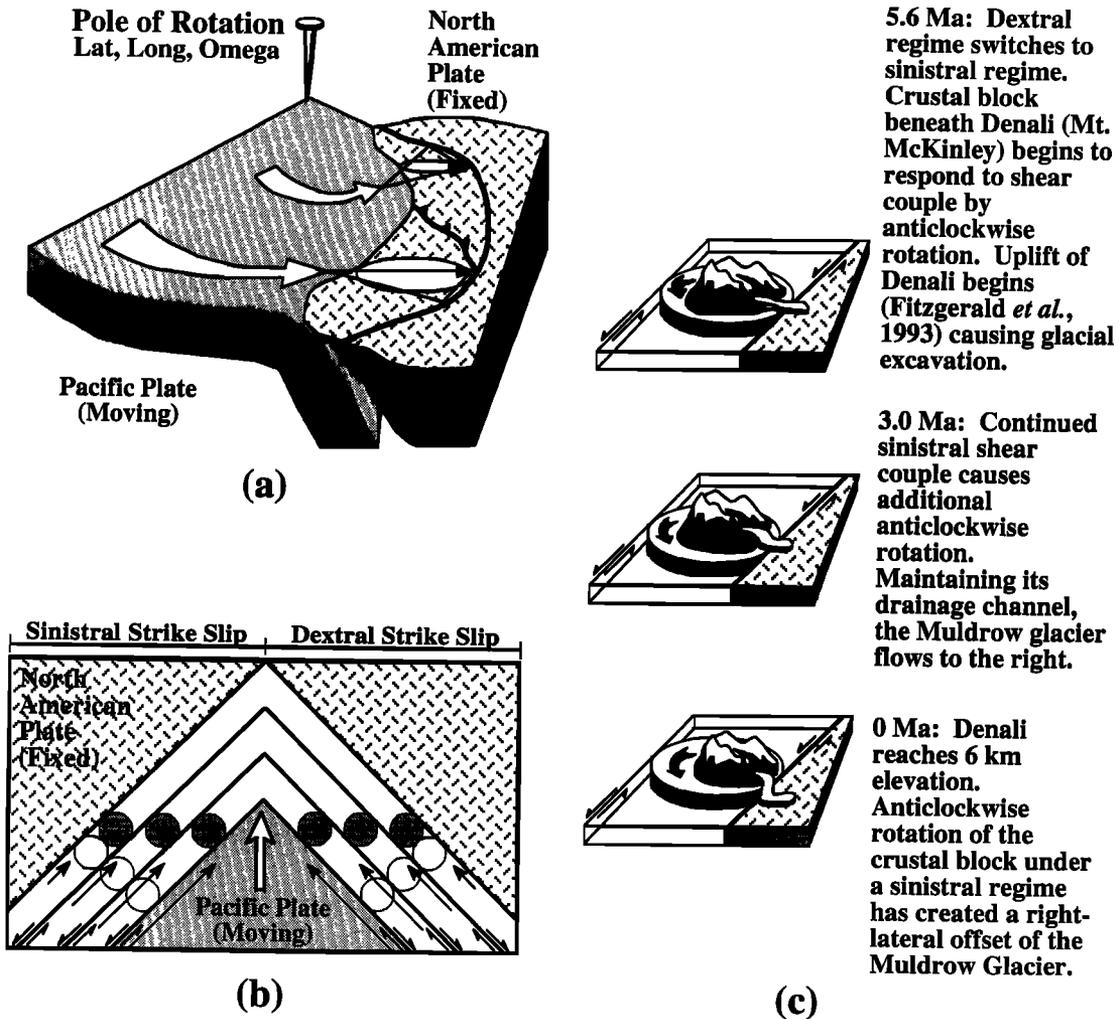
(c)

Fig. 2. (a) Schematic diagram showing a generalized tectonic situation where both dextral and sinistral sense of shear might result from oceanic plate versus continental plate oblique plate tectonic convergence. Space problems are alleviated by intervening structures, such as the thrust fault shown. Note the different senses of the tangential components of the two vector diagrams. (b) Block diagram (Beck's Ball Bearings, modified after Beck [1980, 1989] shows conceptually how both clockwise and counterclockwise rotations of individual blocks could be expected along a single strike-slip fault as a function of fault geometry and the angle of convergence. (c) Sequence showing how counterclockwise rotation of a block trapped within a left-lateral shear couple and the continued excavation of preexisting drainages might create right-lateral offsets, possibly explaining observed drainage patterns of the Muldrow and Peters Glaciers north of Denali (Mount McKinley).

Lewis et al. [1988] ascribed the sense of deformation to inherited pre-Eocene structures. We speculate that similar processes have operated in southern Alaska on crustal scales. Given the obliquely convergent plate tectonic regimes, the significant length of the associated subduction zones, and the systematically variable plate boundary geometry, it is reasonable to expect dextral and sinistral senses of shear along the southwest and southeast coasts of Alaska during the Cenozoic. In addition, given the mature age of the both the southern Alaska subduction zone and the DFS, it is also likely that much of the associated clockwise and counterclockwise rotations took place during the early development of the system.

REGIONAL GEOLOGY

Much of the known kinematic history of the Alaskan terranes is based upon paleomagnetic studies, which have delineated mobile and less mobile terranes throughout much of Alaska. The DFS, extending from southeastern Alaska into south central Alaska, and partly crosscutting the Alaska Range complex (Figure 1), would appear to separate the southern, truly allochthonous terranes from para-autochthonous or even autochthonous terranes to the north.

South of the DFS lie Wrangellia, the Peninsular terrane, and most of the Alaska Range complex. From paleomagnetic and

paleontologic studies, both Wrangellia and the Peninsular terrane are suspected to have undergone substantial northward latitudinal translation [Packer, 1972; Hillhouse, 1977; Panuska and Stone, 1981; Stone, 1982; Stone et al., 1982; Panuska and Stone, 1985; von Huene et al., 1985] and may have been accreted to terranes of continental affinity north of the DFS as early as mid to Late Cretaceous [Plafker et al., 1989]. The Alaska Range complex encompasses parts of Wrangellia and the Peninsular terrane [Stone and Wallace, 1987] as well as many structural slivers and terrane fragments, many of which may also have been translated significant distances [Jones et al., 1982]. Grantz et al. [1991, p. 6-7], citing what they consider to be "the most reliable and representative paleomagnetic data from Alaska," stated that "the terranes that have a well-documented history of major northward displacement occur south of the Denali fault."

Terranes north of the DFS are generally considered to have formed much closer to their present positions than the terranes south of the DFS [Coe et al., 1985]. Dissenting views are presented by Churkin et al. [1982] and Box [1985]. For example, Churkin et al. [1982] describe the Yukon-Tanana terrane as a composite of discrete microterranes possibly accreted to the North American plate at a southerly latitude in Yukon Territory, Canada, prior to the Late Cretaceous and subsequently transported to their present location by strike-slip faulting. Box [1985] suggested that much of Alaska north of the DFS may have resulted from an Early Cretaceous collision of an active volcanic arc with the North American continental lithosphere. However, these interpretations do not seem to be supported by geological or geophysical data.

Hillhouse and Grommé [1982] concluded that all terranes (e.g., the Yukon-Tanana and Nixon Fork terranes), lying beneath or north of the present-day exposures of Paleocene Cantwell Formation (on the north side of the DFS just north of the Denali/Mt. McKinley massif), have undergone no detectable poleward drift relative to the North American craton since the Paleocene. Plumley and Coe [1982, 1983] and Blodgett [1983a, b] suggested independently, on paleomagnetic and paleontologic grounds, that the Nixon Fork terrane has not moved far from its point of origin.

Paleomagnetic data presented by Coe et al. [1985, 1989] support the concept that terranes north of the DFS have not moved greatly from their present-day location. From a paleomagnetic study of lower Cretaceous tuffs in the Yukon Kuskokwim delta region, Globerman et al. [1983] speculated that central and western Alaska were essentially part of the North American continent by Late Cretaceous to Paleocene time. Data from the Nowitna Lava flows (~64 Ma) [Moll et al., 1981] of the Kuskokwim Mountains (near McGrath, Alaska) give a mean direction that is consistent with little or no latitudinal displacement or rotation relative to North America [Coe et al., 1985]. Although Stone et al. [1982] suggested that the present-day Kuskokwim terrane was displaced from a location of ~15° north at ~85 Ma, three out of four localities sampled were near Lake Clark, south of the DFS. Only one site was north of the DFS, near McGrath. The results of this study are therefore somewhat inconclusive with respect to the history of the Kuskokwim terrane north of the DFS. Harris et al. [1987, p. 362] present paleomagnetic data indicating that the Yukon-Koyukak province (between the Brooks Range and the Yukon-Kuskowim Delta) was in place by 56 Ma and "formed part of the accretionary nucleus that served as a backstop for the accreted terranes of southern Alaska." Wallace et al. [1989] suggested that the Yukon

Koyukuk arc was in place by Latest Cretaceous to Early Tertiary times.

"The Cenozoic Denali fault system of Alaska apparently has developed on the already accreted continental margin, partly along an older, Cretaceous suture" [Csejtey et al., 1982, p. 3746]. This conclusion is supported by recent geophysical studies. Labson et al. [1988] and Stanley et al. [1990] reported on magnetotelluric data, suggesting that the metamorphic rocks of the Yukon-Tanana terrane represent a thin-skinned thrust sheet overlying conductive Upper Jurassic and Cretaceous sedimentary rocks. Beaudoin et al. [1992] integrated the electrical data cited above with seismic data from the Trans-Alaska Crustal Transect project, suggesting that the underplating of the Yukon-Tanana terrane occurred before the docking of Wrangellia. Pavlis et al. [1993] suggested that cooling ages within the Yukon-Tanana terrane record tectonic extension. However, this extension was complete by 110 Ma. Hansen [1990] concluded that a large part of the Yukon-Tanana terrane is para-autochtonous with a complex history of "dynamothermal" metamorphism during the middle to late Mesozoic and hence should not be considered suspect. Taken together, these studies would suggest that the Yukon-Tanana terrane and other central Alaskan terranes north of the DFS were in place prior to the accretion of the mobile southern terranes.

On the above evidence, and for the sake of exploring an intriguing hypothesis, we have made the necessarily speculative assumption that the terranes north of the DFS have been effectively anchored, essentially in situ, since the Latest Cretaceous, or at least the Early Tertiary. In our model, the function of these terranes is to provide resistance (a "backstop") against which the stresses generated by plate tectonic convergence were resolved into normal and tangential components. We speculate that the tangential components were primarily responsible for imparting the counterclockwise and clockwise rotations observed in the paleomagnetic record of southern Alaska. The normal stress components were probably absorbed by attenuation and shortening, perhaps initially behind (north of) the backstop, and later within the accreting terranes south of the DFS.

OFFSET HISTORY OF THE DENALI FAULT SYSTEM

At a few places the DFS displays evidence of Holocene activity. Between some segments, pre-Holocene offset is documented by correlated geologic formations and intrusions separated by apparent strike-slip motion. However, well-documented examples of offsets across the DFS, particularly at its western end, are not plentiful.

Holocene scarps up to 6 m high characterize the Holitna, Togiak-Tikchik, and Farewell fault traces [Grantz, 1966]. The McKinley strand of the DFS displays right-lateral horizontal offsets of 50 to 60 m and 6 to 10 m of vertical throw, north-side-up since 10,000 years ago [Stout et al., 1973]. The western end of the Shakwak fault segment exhibits 87 m of right-lateral offset that occurred during the Holocene [Plafker et al., 1977]. After a literature study of the six major strands of the DFS, Lanphere [1978] concluded that only the McKinley strand and the western end of the Shakwak fault of the DFS exhibit a reliable history of Holocene offset. Savage et al. [1981] and Plafker et al. [1989] suggested contemporary slip rates along the central Denali fault (sites 9 and 10, Figure 1) to be of the order of 1-2 cm/yr.

On the basis of separation of Cretaceous rocks and regional drag features, Grantz [1966] concluded that the Holitna and Togiak/Tikchik segments moved 20 - 30 km in a right-lateral sense during Late Cretaceous and Cenozoic time. Reed and Elliot [1968] noted east-northeast drag features south of the Farewell fault, implying right-lateral offset. Grantz [1966] suggested ~100 km slip has occurred on the Farewell fault since the Late Cretaceous. However, Lanphere [1978, p. 821] noted that the western end of the DFS displays "little evidence for the more than 300 kilometers of Tertiary offset recognized elsewhere on the system". There appear to be no published accounts attempting a rigorous correlation of specific formations or intrusions along the western end of the DFS.

Warhaftig [1958] and Warhaftig et al. [1975] demonstrated that significant right-lateral movement of the Hines Creek strand of the DFS is pre-Paleocene (and probably pre-Late Cretaceous) in age. Their work led Lanphere [1978] to suggest that the Hines Creek segment should be considered an older structure, not part of the DFS. South of the Hines Creek strand, major right-lateral displacements may have occurred along the McKinley strand since the Tertiary. The strongest evidence supporting Tertiary movement along the McKinley strand is the offset of the McGonagall pluton relative to the Foraker pluton, requiring 38 km right-lateral offset since 38 Ma The two plutons were correlated by Reed and Lanphere [1974, p. 1883] on the basis of "nearly identical mineralogy and chemistry" and K-Ar and $^{40}Ar/^{39}Ar$ biotite and hornblende age determinations suggesting both simultaneous intrusion ages and similar cooling histories.

Forbes et al. [1973a, b], Turner et al. [1974] and Nockleberg et al. [1985] suggested that 300 to 400 km of right-lateral displacement (separating the Ruby Range and the McLaren Metamorphic Belt) occurred since Early Cretaceous along the McKinley, Dalton, and Shakwak segments of the DFS. Also, Eisbacher [1976] correlated the Nutzina sequence with sedimentary rocks in the Dezadeash basin. If so, these packages of Mesozoic flysch rocks along the DFS would record a minimum of 300 km right-lateral offset since the Eocene [Eisbacher, 1976] or at least since the Paleocene [Lanphere, 1978]. Stout and Chase [1980] noted that these last two offset estimates tend to independently correlate one another.

The above summary clearly shows that there are few solid constraints upon the offset history of the DFS. Along different segments of the DFS, the amount and timing of offset varies by an order of magnitude, from estimates of tens of kilometres for the western end to hundreds of kilometers for the eastern end. In particular, the system west of the Denali/Mount Mckinley massif is poorly studied, and its offset history is not well constrained.

THE OROCLINE HYPOTHESIS

Carey [1955] suggested that most of Alaska pivoted counterclockwise 28° about a point north of the Gulf of Alaska, opening the Canada basin north of Alaska and bending the Alaskan mountain ranges (and presumably the trace of the DFS) into their present arcuate geometries. Several authors built upon Carey's initial hypothesis. One set of models calls upon a late Jurassic to mid-Cretaceous tectonic event opening the Canada basin and causing Brooks Range thrusting [Rickwood, 1970; Tailler, 1973; Mayfield et al., 1983]. Other models accomplish bending by requiring 40° to 55° counterclockwise rotation of individual fault-separated blocks in

central and southern Alaska, accompanied by adjustments in northern Alaska [Grantz, 1966; Patton and Tailler, 1977]. Although a simple orocline theory is now considered unlikely [Coe et al., 1989], the concept of large-scale rotations of western Alaska is still considered viable.

Coe et al. [1985] and Coe et al. [1989] presented a case for oroclinal bending, by "mega-kinking," based upon the predominantly counterclockwise paleomagnetic rotations observed in southwest Alaska. Coe et al. [1989] cited studies in the Bristol Bay region, the Lake Clark region, the Lower Yukon River region, and the Blackburn Hills (in southwestern and western Alaska), that documented predominantly counterclockwise rotations. Additional studies in the Cantwell Basin, the Talkeetna Mountains, and the McGrath region (in central, south central, and western Alaska), though less well constrained, also suggested counterclockwise rotations have occurred. Assuming that the western end of the DFS was, and is, a right-lateral transform fault, Coe et al. [1985, 1989] interpreted the counterclockwise rotations to reflect the effects of continental scale enechelon kink folding, a result of convergence between North America and Eurasia. However, Scholl and Stevenson [1991] suggested, as do we, that a convincing explanation for the curvature of geotectonic structures in Alaska need not invoke oroclinal bending.

TECTONIC MODEL

Paleomagnetic data comprise the most compelling evidence supporting the various orocline models. However, we suggest an alternative hypothesis integrating seafloor spreading models and onshore paleomagnetic data. Our model, advancing the currently heretical notion that the western end of the DFS has been strongly (but not totally) influenced by sinistral shear, permits adjacent small-block clockwise and counterclockwise rotations in southern Alaska to peacefully coexist and predicts an offset history for the DFS that allows different amounts of apparent offset to be observed along the trace of the fault system.

Oceanic plate/continental plate relative motion vectors (RMVs) calculated for southern Alaska suggest that the Late Cretaceous and Cenozoic DFS was driven by both right-lateral and left-lateral tangential components. West of the central arc apex, left-lateral components dominated, while east of the apex a primarily right-lateral regime was in place (Table 1[2] in the microfiche and Figure 3). Offset across the DFS was a function of convergence direction of the offshore oceanic plate (Pacific or Kula) and the local backstop azimuth. If so, small crustal blocks in south-central Alaska would have resided in a dominantly left-lateral tectonic environment, conducive to counterclockwise rotation, while counterpart blocks in southeastern Alaska would be affected by a dextral, clockwise shear regime. The model also predicts Cenozoic "partitioning" of the western end of the DFS into regions of left-lateral and right-lateral shear, providing a mechanism to explain localized, less common clockwise rotations.

The model requires three principal assumptions: 1. The DFS has existed since the latest Cretaceous, and possibly

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[2] Tables 1 and 2 are available with entire article on microfiche. Order from the American Geophysical Union, 2000 Florida Avenue, N.W., Washington, DC 20009. Document T93-003; $2.50. Payment must accompany order.

earlier, with much of its present day arcuate shape intact. This assumption is supported by Stout and Chase [1980], who argued that the small circle outline of the central part of the DFS is an intrinsic feature of the fault system itself, and by Csejtey et al. [1982], who suggested that the development of the Cenozoic DFS followed an older terrane suture line. However, Coe et al. [1989] point out that on a large scale, the fit of the DFS to small circles is not very good, and that accretion of terranes south of the DFS during the late Cretaceous and early Tertiary may have indented and/or accentuated the arcuate shape of the DFS. 2. The Yukon-Tanana terrane and other terranes north of the DFS formed an existing backstop against which the southern terranes were accreted. As described above, the northern terranes are not suspected of having undergone significant latitudinal transport relative to North America, while the paleomagnetic documentation of exotic travel histories for the southern terranes is, essentially, beyond dispute. Combining the first two assumptions, the trace of the DFS thus marks, in a gross sense, the trace of the backstop margin. 3. Relative motion vectors (RMVs) calculated from the models of Engebretson et al. [1985] and Kelley [1993], for various places along the above backstop margin are representative of the local stresses imposed at the DFS backstop margin. This assumption incorporates additional uncertainties. The RMV resultants will always be maximum values as coupling between converging plates is certainly less than 100% efficient. The accretion of the southern terranes may have occurred as a series of discrete events, modifying the geometry of the the backstop margin. In addition, known structures between the present-day plate margin and the DFS, such as the Lake Clark/Castle Mountain fault, the Fairweather fault, the Bruin Bay fault, and the Border Ranges fault could absorb much of the effective stress. (Indeed, it is possible that these faults are forming a new, concave-northward fault system whose behavior mimics that of the older DFS). Splays to the DFS, such as the Totschunda fault, and thrust faults such as the Broxon Gulch thrust, add additional tectonic complexity. Within these assumptions, we present a speculative model for the tectonic development of Alaska south of the DFS.

METHODS

The relative motion vector (RMV) V of a point P on plate B relative to plate A may be calculated as follows:

$$V_{global} = \omega R(E \times P)$$

where E is the Euler pole of rotation, ω is the angular rotation rate, and R is the radius of the Earth. Conversion from global coordinates to local cartesian coordinates is accomplished by a 3 x 3 trigonometric matrix T:

$$V_{local} = [T]V_{global}$$

Details of the method may be found in Cox and Hart [1986, p. 155-156]. The resultant relative motion vector (RMV) describes the interaction of plate B (e.g., the Pacific or Kula plate) relative to fixed-in-space plate A (e.g., North America/Alaska). Appropriate trigonometry using the angle between the RMV and the perpendicular to the backstop (e.g., the azimuth of the subduction zone or strike-slip fault

separating plate A and plate B) provides the tangential component of motion at the plate margin (Figure 2).

Engebretson et al. [1985] presented a plate tectonic model for the Pacific Ocean basin that permitted a quantitative assessment of the interaction between the subducting oceanic plates and the continental margin. Their model is dependent on the fundamental assumptions that hotspots have remained fixed (with respect to themselves) relative to the rate of motion of the overriding lithospheric plates and that sea floor spreading rates between the existing Pacific plate and its subducted neighbors were symmetric and can be described by synthetic isochrons. Errors in location of various components of the model summed up to a total uncertainty of 900 km for 100 Ma [Engebretson et al., 1985]. New data have helped reduce some of these uncertainties. Lonsdale [1988] reinterpreted the history of the Kula plate, documenting a significant period of asymmetric spreading, after which Kelley [1993] integrated Lonsdale's findings into a new model, also incorporating a revised time scale from Cande and Kent [1992].

Although uncertainties created by slight variations in backstop geometry significantly exceed the differences in RMVs calculated with the two plate tectonic models, we have used the up-to-date poles of Kelley [1993]. With these poles, RMVs were calculated at 14 selected points along the DFS (Figure 1) for 11 time periods. In addition, RMVs were calculated for locations along the Kaltag/Tintina fault system, the Iditarod/Nixon Fork fault, the Fairweather/Castle Mountain fault, and at today's Alaska/Pacific plate margin (Figure 1). The results are presented in Figures 3, 4, and 5, and Tables 1 and 2 in the microfiche.

The magnitude and sign of the tangential components of the RMV resultants are sensitive to the azimuth of convergence, and thus the orientation of the backstop. For this study we measured azimuths of the DFS from the State of Alaska geologic map [Beikman, 1980] and, by assumption, computed RMVs as if the DFS were the plate margin. For the sake of completeness, we have calculated RMVs from 83 Ma to the present. However, the uncertainties of our analysis increase with the age of the margin. When discussing the implications of our model, we bear in mind that speculation achieves new heights with increasing age.

In view of the above assumptions and the known geological complexities, we emphasize that the quantitative results this analysis presents are maximum estimates for an assumed plate margin geometry. The RMV data should not be viewed as absolute. Rather, we present this analysis as a qualitative, conceptual framework that may perhaps lead to a fieldwork-based reinterpretation of the offset history of the DFS.

DISCUSSION

The variable sense of shear along the DFS predicted by the model may be reflected in paleomagnetic data from southwest and south central Alaska. In this section we discuss the RMV data generated from specific locations along faults comprising the DFS in the context of regional geology and associated paleomagnetic studies.

The Togiak/Tikchik and Holitna segments of the DFS runs from Bristol Bay to a point ~150 km inland, at azimuths between 210 and 220 (sites 1-3, Figure 1). RMV calculations for sites 1 (azimuth 210) , 2, and 3 (azimuths 220° and 225°) show a consistent left-lateral tangential component between 83
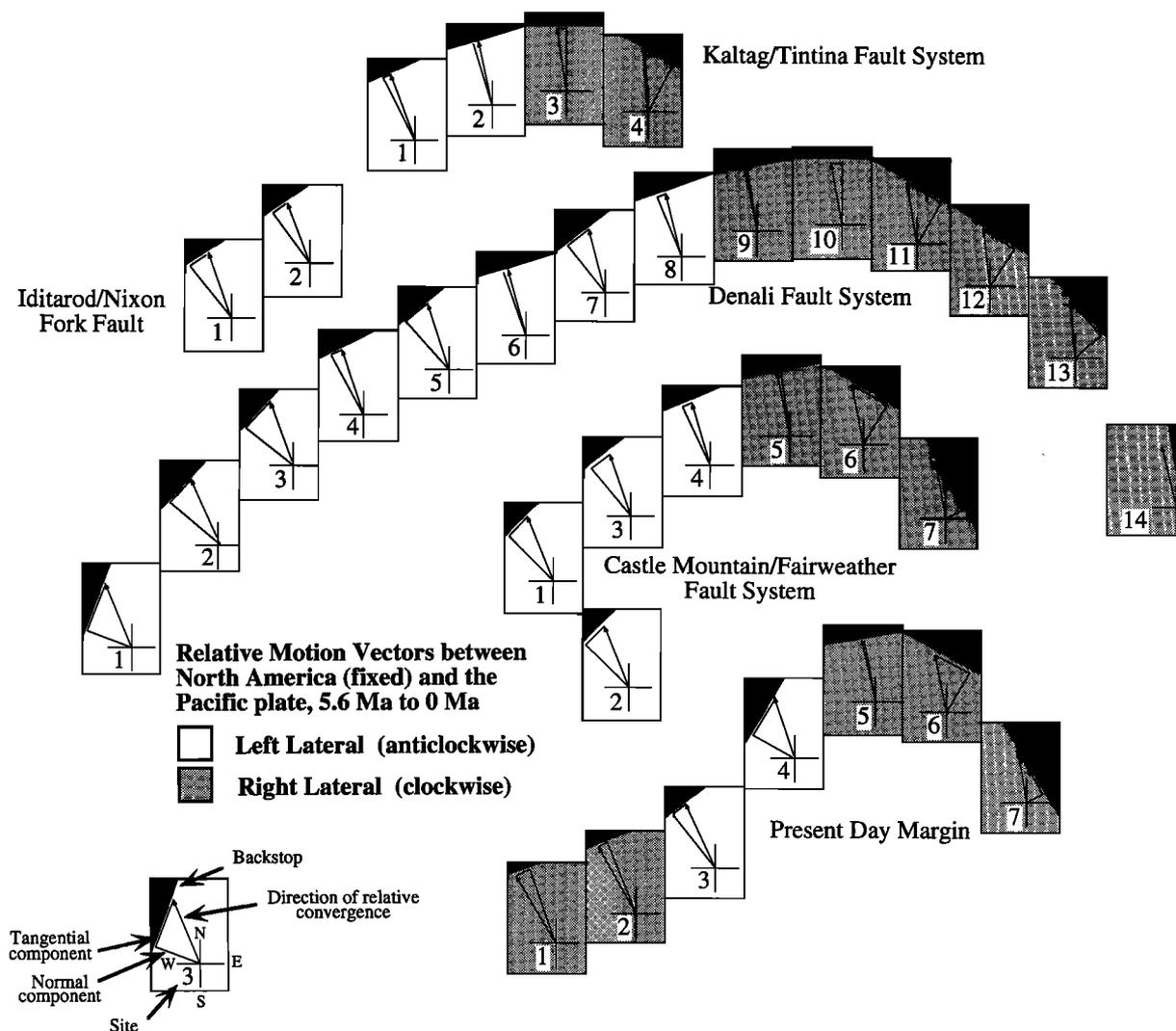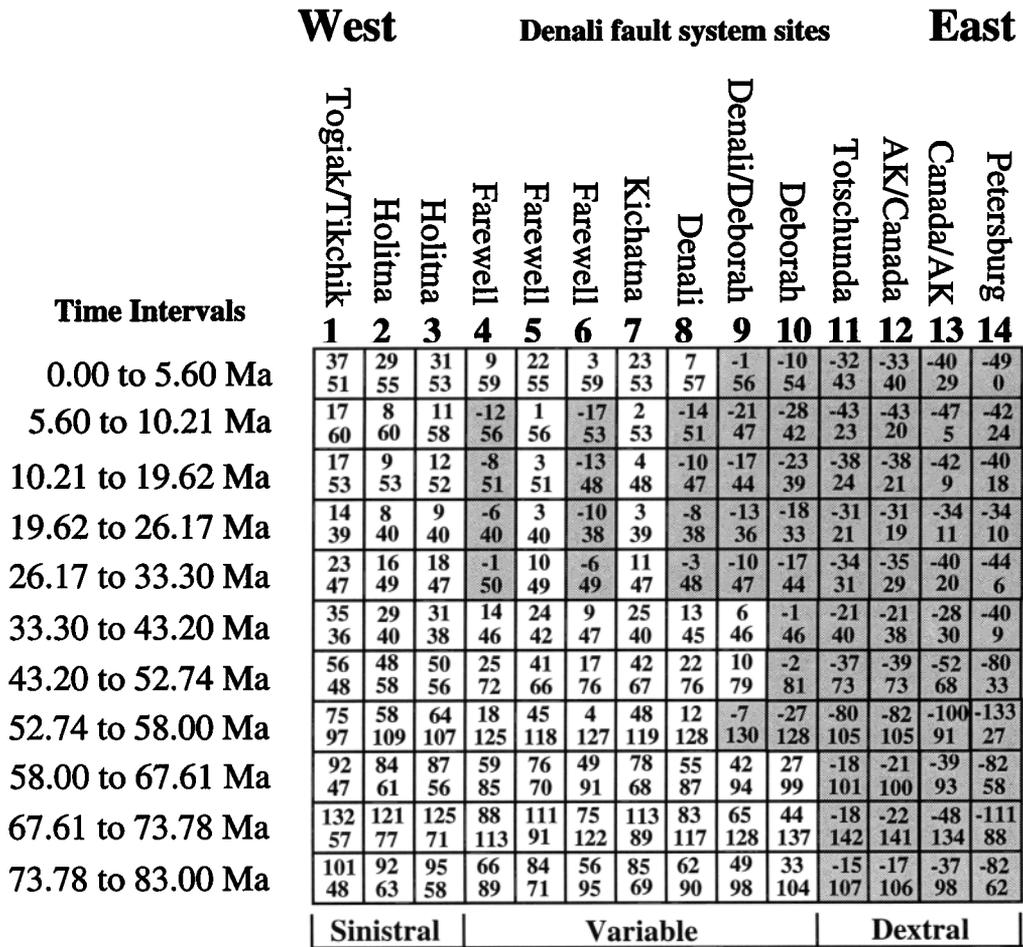
Fig. 3. Schematic diagram showing RMV diagrams along the major curved faults of Alaska between 5.6 Ma and the present. Note that tangential slip velocities are greatest at either end of a given curved fault system, becoming more compressional toward the "armpit" of Alaska. Generation of tangential and normal vectors utilizes plate tectonic models of Kelley [1993] and Engebretson et al. [1985], as discussed in the text.

Ma and the present (Table 1 in the microfiche and Figure 3). The region between the sites is structurally complex, with many semiorthogonal crosscutting fault patterns [Beikman, 1980]. Paleomagnetic data in this area are limited. Globerman and Coe [1983] reported counterclockwise rotations from an upper Cretaceous unnamed volcanic series in the Togiak terrane near north Bristol Bay, results consistent with left-lateral shear.

The Farewell fault (sites 4-7, Figure 1) connects the western and central portions of the DFS, crosscutting both Cretaceous and Paleozoic rocks along its trace [Beikman, 1980]. Sites 4, 5, and 6 were selected to investigate the effect of a gentle bend in fault geometry (Figure 6). At site 4 (azimuth 242°), a right-lateral RMV tangential component is favored between 33.3 and

5.6 Ma (Figure 3). A compressional regime is implied between sites 1 and 4 during this time period, providing a possible mechanism for generating some of the structural complexity near the Bristol Bay region by thrusting and reverse faulting. Site 5 (placed on the most northerly trending segment of the bend in the Farewell fault; backstop azimuth 230°) displays consistent left-lateral tangential components from 83 Ma to the present. Site 6 (azimuth 250°) favors right-lateral shear between 33.3 Ma and 5.6 Ma. Tangential components are quite small; in this area, strain accumulation may not always have been relieved by strike-slip motion. Csejtey et al. [1982] suggested that Tertiary right-lateral strike-slip displacement dies out along the Farewell fault, replaced by

West　　Denali fault system sites　　East

Time Intervals	1 Togiak/Tikchik	2 Holitna	3 Holitna	4 Farewell	5 Farewell	6 Farewell	7 Kichatna	8 Denali	9 Denali/Deborah	10 Deborah	11 Totschunda	12 AK/Canada	13 Canada/AK	14 Petersburg
0.00 to 5.60 Ma	37/51	29/55	31/53	9/59	22/55	3/59	23/53	7/57	-1/56	-10/54	-32/43	-33/40	-40/29	-49/0
5.60 to 10.21 Ma	17/60	8/60	11/58	-12/56	1/56	-17/53	2/53	-14/51	-21/47	-28/42	-43/23	-43/20	-47/5	-42/24
10.21 to 19.62 Ma	17/53	9/53	12/52	-8/51	3/51	-13/48	4/48	-10/47	-17/44	-23/39	-38/24	-38/21	-42/9	-40/18
19.62 to 26.17 Ma	14/39	8/40	9/40	-6/40	3/40	-10/38	3/39	-8/38	-13/36	-18/33	-31/21	-31/19	-34/11	-34/10
26.17 to 33.30 Ma	23/47	16/49	18/47	-1/50	10/49	-6/49	11/47	-3/48	-10/47	-17/44	-34/31	-35/29	-40/20	-44/6
33.30 to 43.20 Ma	35/36	29/40	31/38	14/46	24/42	9/47	25/40	13/45	6/46	-1/46	-21/40	-21/38	-28/30	-40/9
43.20 to 52.74 Ma	56/48	48/58	50/56	25/72	41/66	17/76	42/67	22/76	10/79	-2/81	-37/73	-39/73	-52/68	-80/33
52.74 to 58.00 Ma	75/97	58/109	64/107	18/125	45/118	4/127	48/119	12/128	-7/130	-27/128	-80/105	-82/105	-100/91	-133/27
58.00 to 67.61 Ma	92/47	84/61	87/56	59/85	76/70	49/91	78/68	55/87	42/94	27/99	-18/101	-21/100	-39/93	-82/58
67.61 to 73.78 Ma	132/57	121/77	125/71	88/113	111/91	75/122	113/89	83/117	65/128	44/137	-18/142	-22/141	-48/134	-111/88
73.78 to 83.00 Ma	101/48	92/63	95/58	66/89	84/71	56/95	85/69	62/90	49/98	33/104	-15/107	-17/106	-37/98	-82/62

Sinistral	Variable	Dextral

-15 / 63

15 km/my right-lateral tangential component and 63 km/my normal component predicted from model. Dextral shear couple predicts clockwise rotations.

22 / 71

22 km/my left lateral tangential component and 71 km/my normal component predicted from model. Sinistral shear couple predicts anticlockwise block rotations.

Fig. 4. Block diagram synthesizing RMV data for the Denali fault system in space and time. Note that the western end of the DFS has experienced entirely sinistral tangential components, while the eastern end has always been characterized by dextral components. The partitioning of the middle regions into sinistral and dextral regimes is a function of fault/backstop geometry (see Figure 6). Source data for the computation of tangential and normal vectors are from plate tectonic models of Kelley [1993] and Engebretson et al. [1985], as discussed in the text.

reverse faulting. The large normal components of the RMV data would tend to support their view.

Sites 4, 5, and 6 (Figure 6) demonstrate the azimuth sensitivity of our analysis. The azimuths of relative convergence along the western end of the DFS are close to the "crossover azimuth," where tangential components change from sinistral to dextral. Small variations in plate convergence

direction, or minor geometric irregularities in the backstop, could be sufficient to reverse the sense of shear and create opposing local stress regimes. This appears to be reflected in the paleomagnetic record of southwestern Alaska: of seven studies reported by Coe et al. [1989], six demonstrated counterclockwise rotations while one records a weak apparent clockwise rotation. Thrupp and Coe [1986] also showed that

West   East
Kaltag-Tintina fault sites

Time Intervals	Unalakleet 1	Yukon 2	Yukon East 3	Ak/Canada 4
0.00 to 5.60 Ma	5 / 61	6 / 58	-7 / 54	-29 / 43
5.60 to 10.21 Ma	-14 / 56	-13 / 51	-24 / 42	-39 / 24
10.21 to 19.62 Ma	-11 / 50	-10 / 47	-20 / 39	-35 / 24
19.62 to 26.17 Ma	-9 / 39	-9 / 38	-17 / 33	-29 / 21
26.17 to 33.30 Ma	-5 / 50	-4 / 48	-15 / 44	-32 / 31
33.30 to 43.20 Ma	11 / 48	11 / 46	0 / 46	-19 / 40
43.20 to 52.74 Ma	14 / 74	15 / 77	-4 / 81	-39 / 73
52.74 to 58.00 Ma	0 / 125	-1 / 128	-30 / 128	-82 / 105
58.00 to 67.61 Ma	49 / 91	50 / 91	27 / 99	-18 / 101
67.61 to 73.78 Ma	74 / 122	75 / 122	44 / 137	-19 / 142
73.78 to 83.00 Ma	57 / 96	58 / 94	34 / 104	-14 / 107

West   East
Iditarod-Nixon Fork fault sites

Time Intervals	West 1	East 2
0.00 to 5.60 Ma	25 / 55	14 / 57
5.60 to 10.21 Ma	-4 / 59	-6 / 54
10.21 to 19.62 Ma	-6 / 52	-4 / 49
19.62 to 26.17 Ma	5 / 40	-3 / 39
26.17 to 33.30 Ma	12 / 49	3 / 49
33.30 to 43.20 Ma	26 / 42	18 / 44
43.20 to 52.74 Ma	41 / 63	29 / 72
52.74 to 58.00 Ma	47 / 115	25 / 125
58.00 to 67.61 Ma	78 / 68	64 / 81
67.61 to 73.78 Ma	113 / 88	95 / 107
73.78 to 83.00 Ma	87 / 70	72 / 83

West   East
Bear Mt./Castle Mt./Fairweather fault sites

Time Intervals	Naknek/King Salmon 1	Kodiak Island 2	Western Cook Inlet 3	Anchorage 4	Western Chugach 5	Eastern Chugach 6	Baranof Island 7
0.00 to 5.60 Ma	23 / 57	29 / 54	22 / 55	9 / 57	-3 / 56	-34 / 41	-48 / 12
5.60 to 10.21 Ma	1 / 61	6 / 60	0 / 56	-13 / 53	-23 / 47	-45 / 20	-48 / 13
10.21 to 19.62 Ma	4 / 54	9 / 53	3 / 51	-9 / 49	-19 / 44	-40 / 21	-44 / 8

West   East
Aleutian Trench (present day Pacific/North American plate boundary)sites

Time Intervals	Western Peninsula 1	Eastern Peninsula 2	Kodiak Island 3	Gulf of Alaska 4	Western Chugach 5	Southeastern Chugach 6	Petersburg 7
0.00 to 5.60 Ma	-19 / 65	-10 / 64	13 / 59	26 / 51	-4 / 55	-35 / 39	-48 / 11
5.60 to 10.21 Ma	-41 / 57	-33 / 58	-11 / 61	3 / 56	-26 / 46	-47 / 19	-48 / 15
10.21 to 19.62 Ma	-33 / 52	-27 / 53	-7 / 54	6 / 50	-21 / 43	-41 / 20	-44 / 10

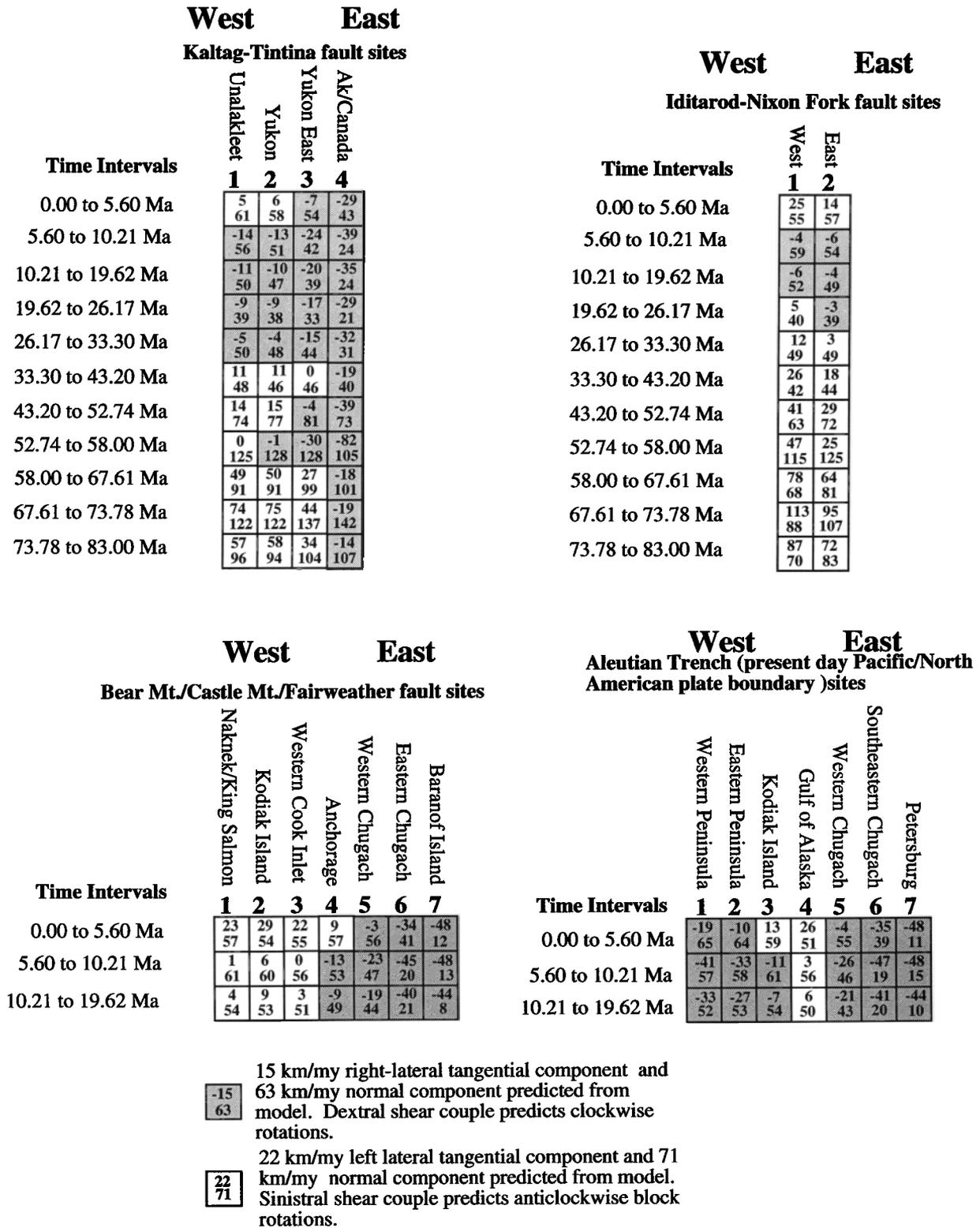| -15 / 63	15 km/my right-lateral tangential component and 63 km/my normal component predicted from model. Dextral shear couple predicts clockwise rotations.
22 / 71	22 km/my left lateral tangential component and 71 km/my normal component predicted from model. Sinistral shear couple predicts anticlockwise block rotations.

Fig. 5. Block diagram synthesizing RMV data for the Kaltag/Tintina, Iditarod-Nixon Fork, Castle Mountain/Fairweather faults, and the present-day North America-Pacific plate boundary, in time and space. Source data for the computation of tangential and normal vectors are from plate tectonic models of Kelley [1993] and Engebretson et al. [1985], as discussed in the text.

Granitic intrusive rocks, undated

Cretaceous volcanic greywacke sandstone and mudstone

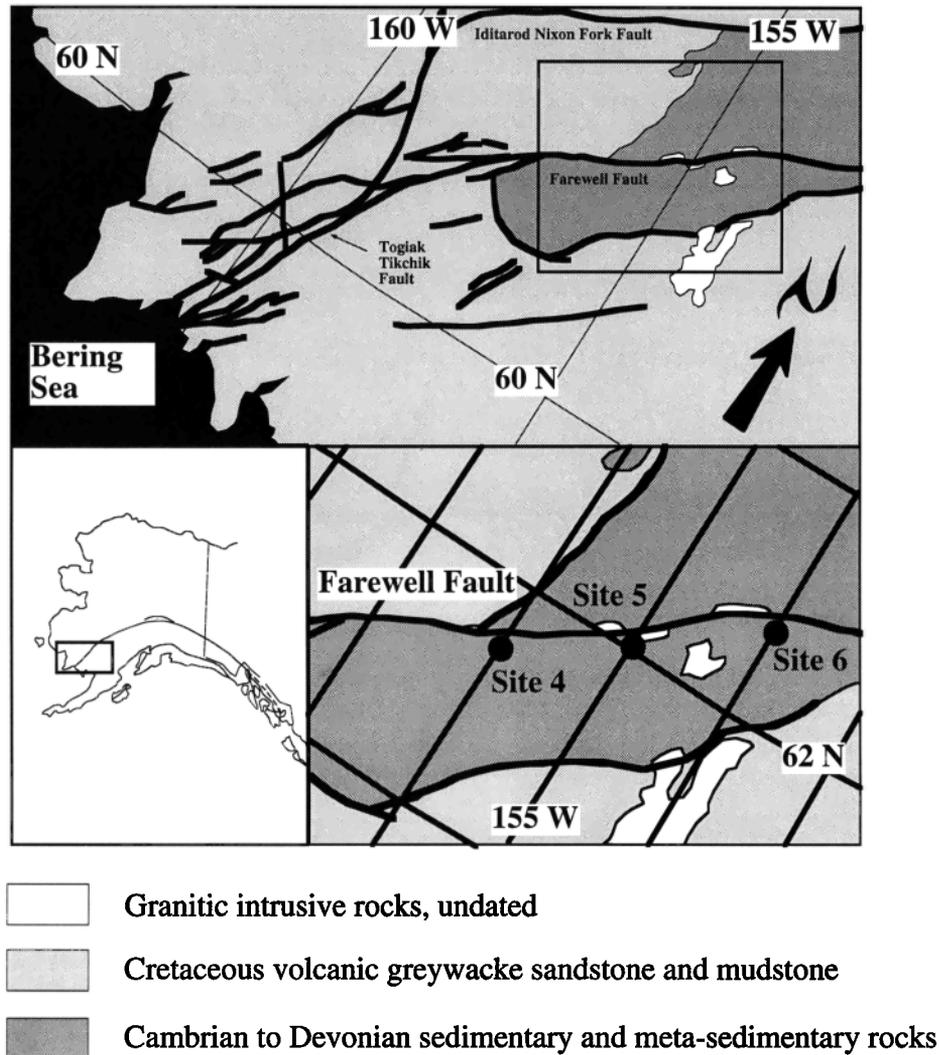Cambrian to Devonian sedimentary and meta-sedimentary rocks

Fig. 6. Schematic geologic map of a portion of the Farewell fault [after Beikman, 1980], showing the fault azimuth dependency of this study. Gentle variations in azimuth can result in conflicting tangential components (see Table 1 in the microfiche).

counterclockwise rotations south of Lake Clark occurred during the Paleocene, a time when large sinistral tangential components would be expected (Figure 3 and Table 1 in the microfiche)

As discussed above, the Hines Creek strand of the Denali fault has probably been inactive for much of the Cenozoic [Lanphere, 1978]. Consequently, for this study, RMVs were generated for the McKinley strand alone (sites 8-10, Figure 1). Strictly speaking, the backstop for the McKinley strand would appear to be composed of many tectonic slivers trapped between the McKinley and the Hines Creek strands [Jones et al., 1982; Hickman et al., 1990]. However, north of the Hines Creek strand is the Yukon-Tanana terrane. This terrane probably acted as the control against which the Late Cretaceous-early Cenozoic DFS developed.

Site 7 (Kichatna Spires, azimuth 232°) has experienced entirely left-lateral tangential components since 83 Ma. Between 33.3 and 5.6 Ma, site 8 (Denali, azimuth 249°)

favored right-lateral components. Site 9 (Denali/Deborah, azimuth 259°) has hosted a dextral component since 33.3 Ma. The dextral RMV regime at the Denali site (site 8) may support the well-known offset correlation of the Foraker and McGonagall plutons [Reed and Lanphere, 1974]. At approximately 5.6 Ma, a change in Pacific-North America plate relative motion [Cox and Engebretson, 1985] caused the tangential component near Denali to change from dextral to sinistral, joining the Kichatna Spires in left-lateral persuasion. Combined with a geometric location near the center of the DFS arc, this increase in (or focusing of) compression may have had a spectacular tectonic result. Apatite fission track data [Fitzgerald et al., 1993] suggest that at ~6 Ma the Denali region experienced rapid uplift and denudation, producing the Denali (Mount McKinley) massif. Another fission track study in the same area [Plafker et al., 1992] also suggests denudation at about this time. This observation is in accord with a model by Schultz and Aydin [1990], showing mean stress due to slip

along the DFS at a maximum inside the apex of the arc.

Paleomagnetic studies in the Denali area are equivocal. Hillhouse and Grommé [1982] suggested an counterclockwise rotation occurred in the Cantwell basin (near site 8), while unnamed lava flows in the Talkeetna Mountains (near site 9) yielded an ambiguous result [Hillhouse and Grommé, 1983; Hillhouse et al., 1983, 1985]. However, in these studies error estimates exceeded the amount of postulated counterclockwise rotation. Another study in the same area by Panuska et al. [1990] suggested a post Eocene counterclockwise rotation, a conclusion consistent with a period of sinistral shear between 53 and 33 Ma. Offset glaciers draining the northern flanks of Denali (e.g., the Muldrow and Peters glaciers) suggest an apparent dextral offset across the Denali strand, although this could be explained by counterclockwise rotation of a block south of the Denali strand resulting from the imposition at 5.6 Ma of a left-lateral shear stress (Figures 2 and 3).

Sites 9 through 14 (Denali/Deborah through Petersburg) have experienced consistent right-lateral RMV components (Figure 3). Site 9 marks a turning point of the dominant shear regime along the DFS. Between site 1 (Togiak/Tikchik) and site 8 (Denali) we calculate for all time intervals primarily left-lateral components with large normal components. The paleomagnetic record, suggesting counterclockwise rotations of the Talkeetna Mountains, Denali National Park, Lake Clark, Bristol Bay, and the McGrath region relative to North America since the Paleocene [Hillhouse et al., 1985; Hillhouse, 1987] would seem to agree. Between sites 10 and 14, RMV data suggest that the DFS has experienced large, right-lateral tangential components. The long-time dextral regime on the eastern end of the DFS is in agreement with the multiplicity of studies that have proposed large right-lateral offsets across the DFS since the Late Cretaceous [e.g. Lanphere, 1978], and with paleomagnetic studies documenting clockwise rotations in the Wrangell Mountains [Hillhouse, 1977, Hillhouse and Grommé, 1984], and the Hound Island volcanics near Petersburg, Alaska [Haeussler et al., 1992].

In summary, RMV data predicting that the western end of the DFS should be characterized largely by sinistral shear appear to be supported by the paleomagnetic record. While large normal RMV components suggest that compression has been a dominant tectonic feature of the western end of the DFS (perhaps reflected in observed vertical fault scarp morphologies), it also appears that the tangential sense of shear is left-lateral, perhaps reflected in the observed counterclockwise block rotations. The same RMV data predict that the eastern end of the DFS has been an active right-lateral strike-slip fault since the Late Cretaceous. The magnitudes of the tangential components along the Shakwak and Dalton faults often exceed those of the normal components; major dextral offsets are favored (and indeed, may be observed in the geologic record). Stout and Chase [1980] proposed a model in which right-lateral motion along the DFS may be described by three rigid plates, whose motions are in small circles defined by the trace of the DFS. Although it may be difficult to consider the lithosphere south of the DFS to be composed of rigid plates, we note that their model is not completely incompatible with ours. Both their Denali and McKinley plates must be, ultimately, driven by coupling with the Pacific plate; our results imply that the McKinley plate would meet additional resistance to the west. This resistance would have to be relieved by additional thrusting. The Broxon Gulch thrust, located near the apex of the DFS arc, can be invoked to accommodate considerable crustal shortening [C. G. Chase, personal communication,

1992]. Stout and Chase [1980] also cite thrusts west of the Broxon Gulch thrust postulated by Csejtey [1976] as additional structures which could have accommodated shortening.

TECTONIC IMPLICATIONS

Because of the lack of constraints in a large number of the assumptions made, the RMV data presented in this paper should be interpreted, geologically speaking, in a conservative, nonquantitative manner. However, as a conceptually novel way of viewing the tectonic framework of southern Alaska, our model inspires us to draw the following observations:

1. The DFS has experienced a consistent left-lateral tangential component along its western end. This sense of shear is conducive to counterclockwise rotation, though the large associated normal component probably resulted in an overall compressive regime.

2. The DFS has shown a consistent right-lateral tangential component along its eastern end since 83 Ma. This sense of shear is conducive to clockwise rotation. RMV tangential components on the eastern end were probably of sufficient magnitude to transport terranes along dextral strike-slip faults.

3. The central portion of the DFS has experienced a variable history. Between 83.0 and 33.3 Ma, the apex of the arc and area west of the apex were subjected to entirely sinistral tangential components. Changes in plate motions after 33.3 Ma resulted in periodic local reversals of the tangential components, permitting variable senses of rotation.

4. As a direct result of its arcuate shape, offsets across the DFS would be expected to differ in magnitude, as well as in sense, between the western and eastern ends of the fault system.

These speculations would imply that the apex of the DFS trace arc would form a point of focus, implying a net compressional regime. This tectonic situation would clearly present a space problem. The arc apex is a logical area to expect the complex thrusting and tectonic slivering reported by Jones et al. [1982]. Additionally, Stout [1972] and Stout and Chase [1980] noted that the Broxon Gulch thrust may be a major tectonic break extending to mantle depths and may have moved simultaneously with the Denali fault. Plafker et al. [1992] suggested that uplift of the central Alaska Range in the Late Cenozoic occurred along a hypothetical northeast striking, northwest dipping thrust splay fault that intersects the Denali strand at an angle of 20°. These thrusts, and perhaps other as yet unrecognized structures, may have relieved the space problem generated by compression.

The post Mesozoic backstop geometry of southern Alaska has undoubtly been influenced by the accretionary history of terranes south of the DFS. As terranes and crustal blocks docked and moved along the backstop of the DFS, local deviations from the convex northward arc we postulate in this paper could create regions where tangential components were the reverse of what our model predicts. However, we suggest that as the southern margin of Alaska continued to build, the DFS arc became more and more the controlling factor to rotation and translation. A corollary of this model compared to observed geologic constraints is that displacements both within terranes [Thrupp and Coe, 1986] and between terranes played an important role in the postaccretionary tectonics of southern Alaska, perhaps through rotation of blocks and attenuation of crust along thrust or high-angle faults.

As the DFS became progressively insulated by the southern accreted terranes, outboard faults may have formed along younger sutures. We speculate that the Fairweather fault

(which truncates the southeasternmost end of the DFS) has joined forces with the Lake Clark-Castle Mountain fault system to create a new variable-shear strike-slip fault. Field observations along the Contact fault [Bol and Roeske, 1993] suggest a record of dextral slip, as do RMVs calculated at representative sites along these faults for the last 20 million years (Table 2, Figure 5). It is likely that crustal blocks against faults south of the DFS have behaved in a similar fashion to those along the DFS throughout the Cenozoic. Net compression in the arc apex and a large region of increased mean stress [Schultz and Aydin, 1990] may be reflected in south central Alaskan topography.

For the sake of completeness, we have extended the model to the Kaltag/Tintina and the Iditarod/Nixon Fork fault systems. RMV resultants suggest that during the early Cenozoic both faults may have experienced sinistral stress regimes (Figure 4). However, both fault systems would appear to have hosted dextral slip components between 26.2 Ma and 5.6 Ma. If the RMV data this far north of the margin can be extended into the early and middle Cenozoic, net westward transport might be predicted between the largely right-lateral Kaltag/Tintina fault and the left-lateral western DFS. This is in accord with a study by Meisling et al. [1987] inferring 130 km right-lateral slip along the Kaltag fault and 200-km right-lateral slip on the Tintina fault since 75 Ma. Present-day components suggest that the Kaltag/Tintina fault system is partitioned in a similar manner as the DFS and that the Iditarod/Nixon Fork fault is influenced by an entirely left-lateral stress field (Figure 3). Shultz and Aydin [1990] showed composite mean stress inside the arc of the Kaltag/Tintina fault system to be lower than inside the DFS for both independent slip and interactive slip models. Their model, combined with the relatively weak tangential components and the complexity of outboard structures, might explain the lack of significant topography inside the arc apex of the Kaltag/Tintina fault system.

One implication of this analysis is that terranes accreted against a backstop subparallel to the western trace of the DFS prior to 33.3 Ma would have experienced a left-lateral regime favorable to counterclockwise rotation. Between 33.3 and 5.6 Ma, structural complexities caused by dextral/sinistral partitioning could have created areas where clockwise rotations were favored. The model provides an alternative mechanism to explain existing paleomagnetic data and obviates the need to invoke oroclinal bending of southwestern and south central Alaska.

CONCLUSIONS

The plate tectonic model of Engebretson et al. [1985] and its direct successor [Kelley, 1993] can be used to place significant constraints upon the evolution of the Denali fault system (DFS) if certain assumptions are made. These assumptions include (1) the geometry of the DFS has remained essentially unchanged since the Late Cretaceous; (2) terranes north of the

DFS provided an existing backstop; (3) relative motion vectors (RMVs) calculated along the DFS are representative of the driving stresses generated by interaction of the Kula or Pacific plates with continental North America. The resulting kinematic model suggests that, while the eastern end of the DFS has probably been characterized by right-lateral shear, the western end of the system has experienced dominantly left-lateral or compressive regimes. Absolute offsets across the DFS may be variable between the southwestern and the southeastern ends of the system, possibly explaining some of the conflicting estimates of strike-slip displacements across the DFS. In western Alaska, along the Togiak/Tikchik, Holitna, and Farewell faults, local supracrustal tectonics may have been controlled by locally conflicting slip vectors. In south central Alaska, near the apex of the DFS arc, opposing senses of shear would have caused space problems. As a result of the approximately 5 Ma change in motion of the Pacific Plate [Cox and Engebretson, 1985; Kelley, 1993], increased mean stress at the arc apex [Schultz and Aydin, 1990] may have resulted in the uplift of the present-day Denali massif [Plafker et al., 1992; Fitzgerald et al., 1993].

The sense of shear calculated using RMVs at any one point along the DFS is dependent upon the azimuth of the fault. Points of convergence and divergence (where right-lateral shear switches to left-lateral shear, or vice versa) are a function of changing backstop geometry as well as varying direction of plate convergence that existed along the DFS in southwest and south central Alaska. As the southern terranes were accreted to the Alaskan margin, their paleomagnetic rotations may have been at least partially determined by the prevailing regime: right-lateral or left-lateral. Paleomagnetic clockwise or counterclockwise rotations would therefore be, in part, a function of where a given block was accreted. In our model, the observed paleomagnetic data are interpreted by local accretion or passive rotation (an apparent rotation acquired during latitudinal translation of a given terrane) rather than invoking a 40°oroclinal bend of much of southwestern Alaska.

In conclusion, we note again that our hypothesis is model-dependent , built upon a number of assumptions. However, the simplicity of the idea intrigues us. While unequivocal proof linking the counterclockwise block rotations of western Alaska with paleosinistral strike-slip shear coupling may be difficult to obtain, we speculate that future field studies along the western ends of the curved fault systems may help clarify the geotectonic development of western Alaska throughout the Cenozoic.

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