LATE-STAGE HIGH-ANGLE FAULTING, EASTERN DOONERAK WINDOW, CENTRAL BROOKS RANGE, ALASKA

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EXPANDED ABSTRACT

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INTRODUCTION

The rocks in the eastern Doonerak Window area, central Brooks Range, Alaska, (fig. 1) have experienced at least three phases of folding, at least one episode of northwest-directed thrusting, and two distinct episodes of high-angle faulting. All rock units [the lower Paleozoic Apoon assemblage (informal name), Devonian Skajit assemblage (informal name), Devonian Hunt Fork Shale and its underlying unnamed calcareous siltstones (Endicott assemblage), Mississippian Kekiktuk Conglomerate, Kayak Shale, and the Mississippian Lisburne Group] have experienced all these phases of deformation.

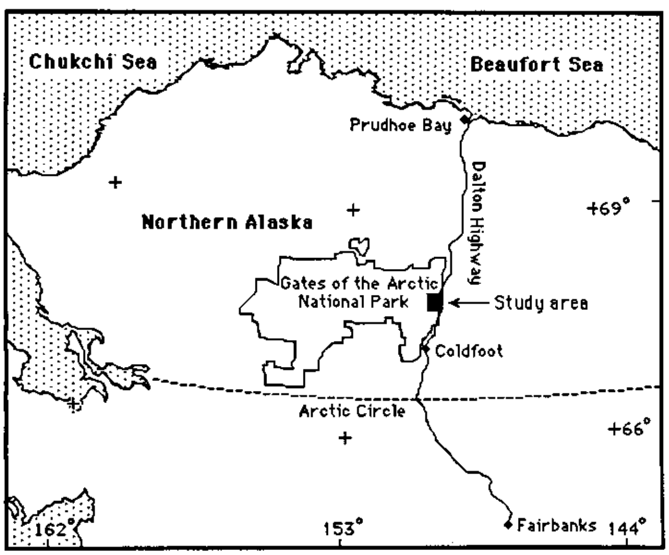

Figure 1. Location map of the eastern Doonerak Window, central Brooks Range, Alaska.

The first phase of folding is characterized by the development of a penetrative slaty cleavage that is axially planar to isoclinal folds. The second phase of folding consists of well-developed chevron-style kink folds of the penetrative first-phase foliation. Gentle to open folding with a weakly developed axially planar cleavage characterizes the third phase of folding. Generally, the third phase cleavage is of the form of close-spaced cleavage or closely spaced joint sets, but uncommonly, it is a weakly developed axially planar crenulation cleavage. This third phase cleavage is subvertical and strikes northwest throughout the study area. It is best developed in the neighborhood of the major east-trending high-angle faults, suggesting that there is a genetic relationship between the third-phase folds and the faults.

FAULTS AND FRACTURES

For the purposes of this study, brittle faults and fractures in the northeastern Doonerak Window are divided into two groups: (1) map-scale faults, and (2) minor faults and fractures. Map-scale faults are, in turn, subdivided into: (1) low-angle reverse or thrust faults, and (2) high-angle faults. No low-angle normal faults were observed in the study area.

Map-Scale Thrust Faults

Numerous northwest-vergent thrust faults (fault planes dip toward the southeast) involve all units in the eastern Doonerak Window area. At least three major levels of décollement are present in this area. One detachment level is at the base of the Devonian clastic successions (the Endicott assemblage), another is within the Kayak Shale (Blarney Creek thrust), and the third is at the base of the Skajit assemblage. The basal thrust of the Endicott assemblage can be traced around the northeastern corner of the Doonerak Window, demonstrating that the Doonerak Window is an actual fenster or window. Oldow and others (1984) and Seidensticker and others (this volume) discuss the Blarney Creek thrust in more detail. The lower Skajit thrust juxtaposes Lower to Middle Devonian(?) marbles and calcschists of the Skajit assemblage over probable Middle to Upper Devonian phyllites, slates, and argillites of the Hunt Fork Shale.

Field relationships in the eastern Doonerak Window area clearly demonstrate that the thrust faulting episode commenced during the formation of the first phase cleavage and was still active throughout second phase fold development. Movement on the faults had ceased before initiation of third phase deformation.

Map-Scale High-angle Faulting

Major east-west-trending high-angle faults cut all rocks in the study area and clearly postdate all other structures (fig. 2). The faults are easily seen as offsets of the more competent rocks: the Skajit marbles, Lisburne Group limestones, Kekiktuk conglomerates, and Hunt Fork quartzites. Tracing the faults through the argillite, phyllite,

Alaskan North Slope Geology, Volumes I and II, 1987
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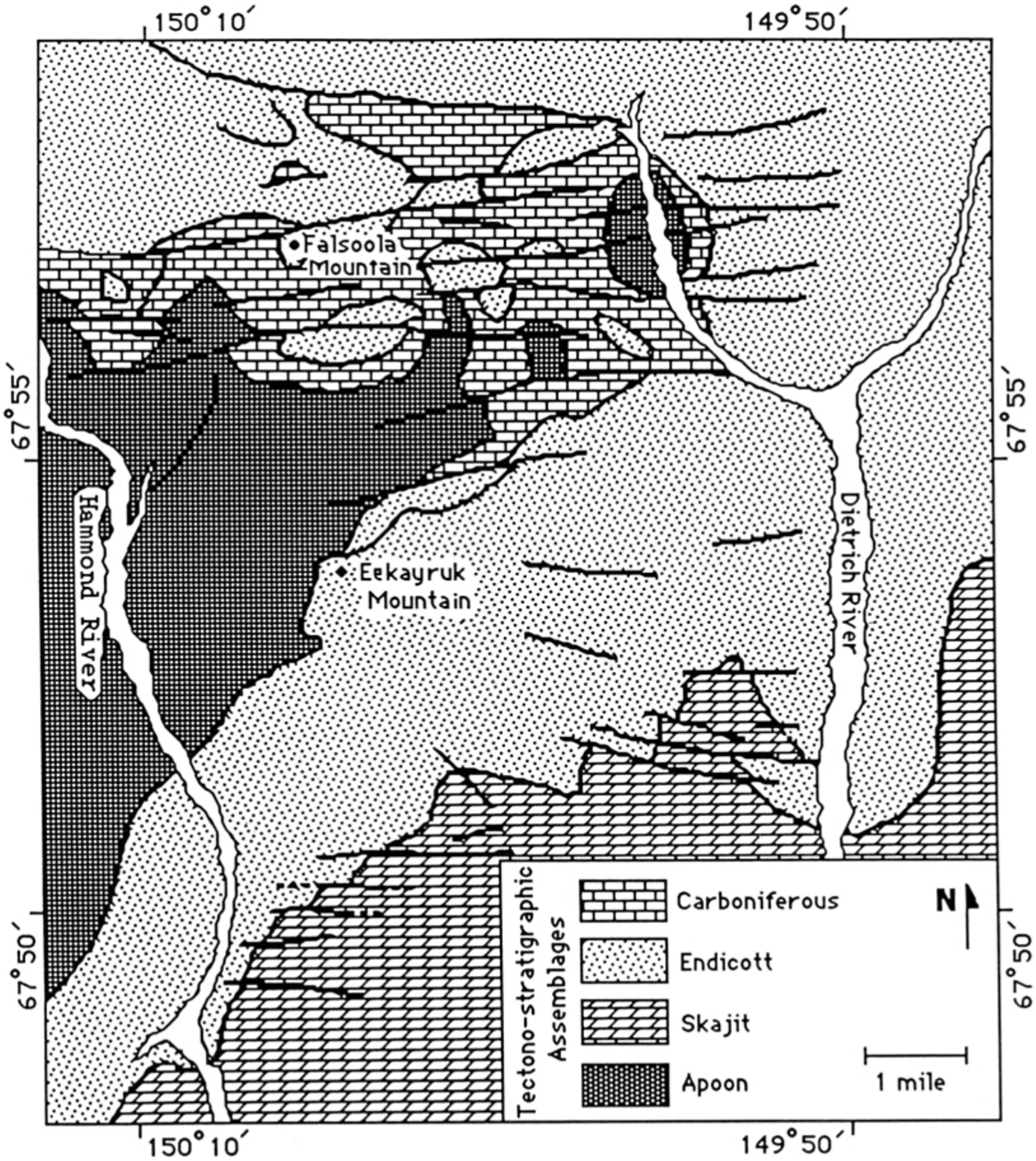


Figure 2. Simplified geologic map showing major tectonostratigraphic assemblages and faults.

and slate sequences of the various rock units is difficult due to the lithologic similarity of these rock types. In these rocks, faults were located along zones of rotated second phase structures and in zones in which third phase deformation was more intense. Slickenside striations on the fault surfaces of these late-stage east-west trending faults are predominantly sub-horizontal.

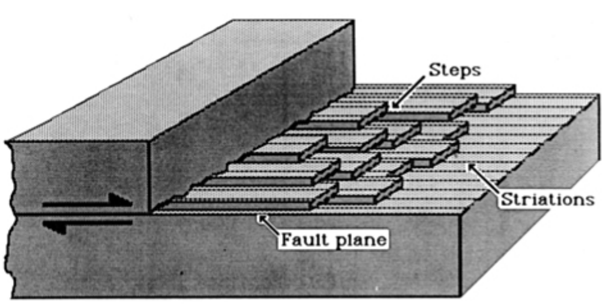


Figure 3. Relationship of fault motion to steps in slickenside striations.

Minor Faults and Fractures

Outcrop-scale high-angle faults and fractures are well-developed throughout the study area. These structures show minor shear displacement; fault throw is generally less than 20 feet (6 m). Only the following types of faults and fractures were used in the structural analysis: a) faults displaying slickenside striations, b) conjugate sets of faults and fractures, and c) en echelon fractures in ductile shear zones.

STRUCTURAL ANALYSIS

A structural analysis was performed on the high-angle faults in order to determine the stress fields operative during formation of these faults. All fault surfaces that displayed well-developed slickenside striations were used in the analysis. The sense of motion on these shear planes was determined by noting the direction of 'steps' on the fault surface (fig. 3). For purposes of this study, any fault with slickenside striations with a rake of less than 45 degrees was called a strike-slip fault; those faults with striation rakes of greater than 45 degrees are considered either reverse or normal faults, depending on the sense of displacement of the fault. Very occasionally, sigmoidal en echelon extension fractures were associated with the faults. These extension fractures were also used to determine the sense of displacement across the shear zone or fault. The orientations of the fault poles (and sense of shear, if known), as well as slickenside striations were plotted on lower-hemisphere equal-area stereonet projections (fig. 5). At various localities in the field area, conjugate fault planes and fractures were observed. Structural analysis of conjugate sets was used to determine stress orientations that existed during formation of the shear plane sets.

Slickenside Striations

Slickenside striations are actually scratched or gouged grooves and ridges that result from friction along the fault plane during fault displacement. The direction of fault motion is parallel to the orientation of the grooves. If the fault surface is a progressively opening extension fissure, slickenside striations will not develop. Instead, vein minerals will deposit in the opened fissure, resulting in oriented, fibrous mineral growths. Both types of structures, the striations on the fault surfaces and the lineations that are the result of oriented growth of calcite or quartz, record the direction of displacement along the fault surface. Where steps occur on the fault surface (fig. 3), the sense of displacement can also be deduced. It should be noted that the slickenside striations record only the last movement on the shear plane, whereas the oriented mineral growths will record the incremental history of movement on the fault that was active during the period when the mineral material was being deposited (Ramsay and Huber, 1983).

En echelon Extension Fractures

Numerous ductile shear zones were observed in the more competent rocks (quartzites, limestones, conglomerates, and marbles). In these structures, the strain gradient is continuous across the zone such that no geometrical discontinuities, i.e. faults, are observed on the scale of an outcrop (Ramsay and Huber, 1983). Often within the ductile shear zones, one finds en echelon, sigmoidal extension fractures (fig. 4). These extension fractures were used to determine the sense of shear displacement of the zone and the approximate value of that displacement (large or small). The sense of displacement is deduced from the change in orientation of the fractures with respect to the shear zone and from the sigmoidal shape which is the result of progressive simple shear (fig. 4). Initially, the fractures are oriented at 45° to the shear zone, perpendicular to the major principal extension direction, σ_3 (Ramsay and Huber, 1983). The major principal compression direction, σ_1, lies in the plane of the fracture and is perpendicular to the intersection of the fracture and the shear zone. The intermediate principal stress direction, σ_2, is perpendicular to the plane containing σ_1 and σ_3. The direction of shear along the zone is perpendicular to σ_2.

Due to progressive simple shear the fractures rotate, but their tips continue to propagate outwards in the direction of σ_1, resulting in the sigmoidal shape of the fractures. When the fractures have experienced a large rotation, the old sigmoidal veins are abandoned and new cross-cutting fractures develop.

Conjugate Faults and Fractures

Conjugate shear planes or faults are defined as a group of faults consisting of two sets that are symmetrically arranged around some other structural feature or about an inferred stress axis. The acute and obtuse bisectors of conjugate shear planes are used to determine the principal stresses that prevailed during formation of these systems of conjugate fractures. The principal stress axes which lead to fracture are related to the faults in the following way: (a) the direction of maximum compression, σ_1, is the acute bisector of the fault planes; (b) the direction of minimum compression (or maximum extension), σ_3, is the obtuse bisector of the planes; and (c) the intermediate compression axis, σ_2, follows the intersection of the faults (Ramsay and Huber, 1983). Theoretical direction of slip along the shear fracture plane will be along a line perpendicular to the intermediate stress axis lying within that shear plane.

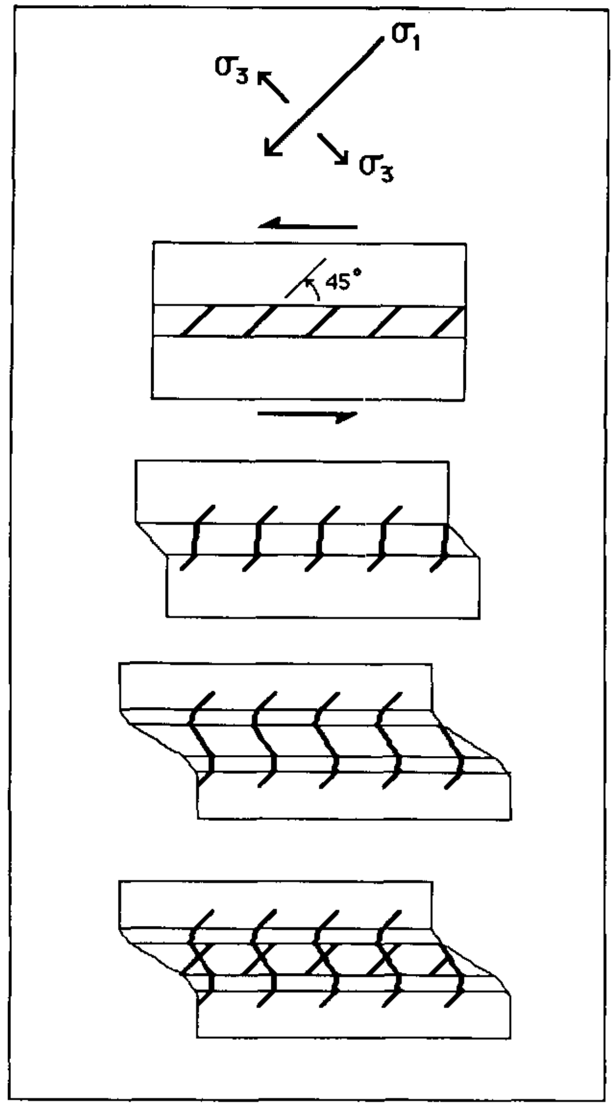


Figure 4. Evolution of sigmoidal en echelon extension fractures (modified from Ramsay and Huber, 1983): (a) Applied stress that leads to shear; (b) En echelon extension fractures form in response to the applied stress field; (c) As shear deformation continues, the fracture tips propogate outwards in direction of 1, while the internal part of the shear zone is rotated by simple shear; (d) With progressive simple shear the fracture tips continue to propogate, while the internal portions rotate further; (e) When initial fractures can no longer rotate, the old fractures are abandoned in favor of a new, cross-cutting set.

RESULTS

When the poles to all fault planes and the slickenside striations are plotted on one stereonet, it becomes clear that one phase of deformation cannot account for all of the data.

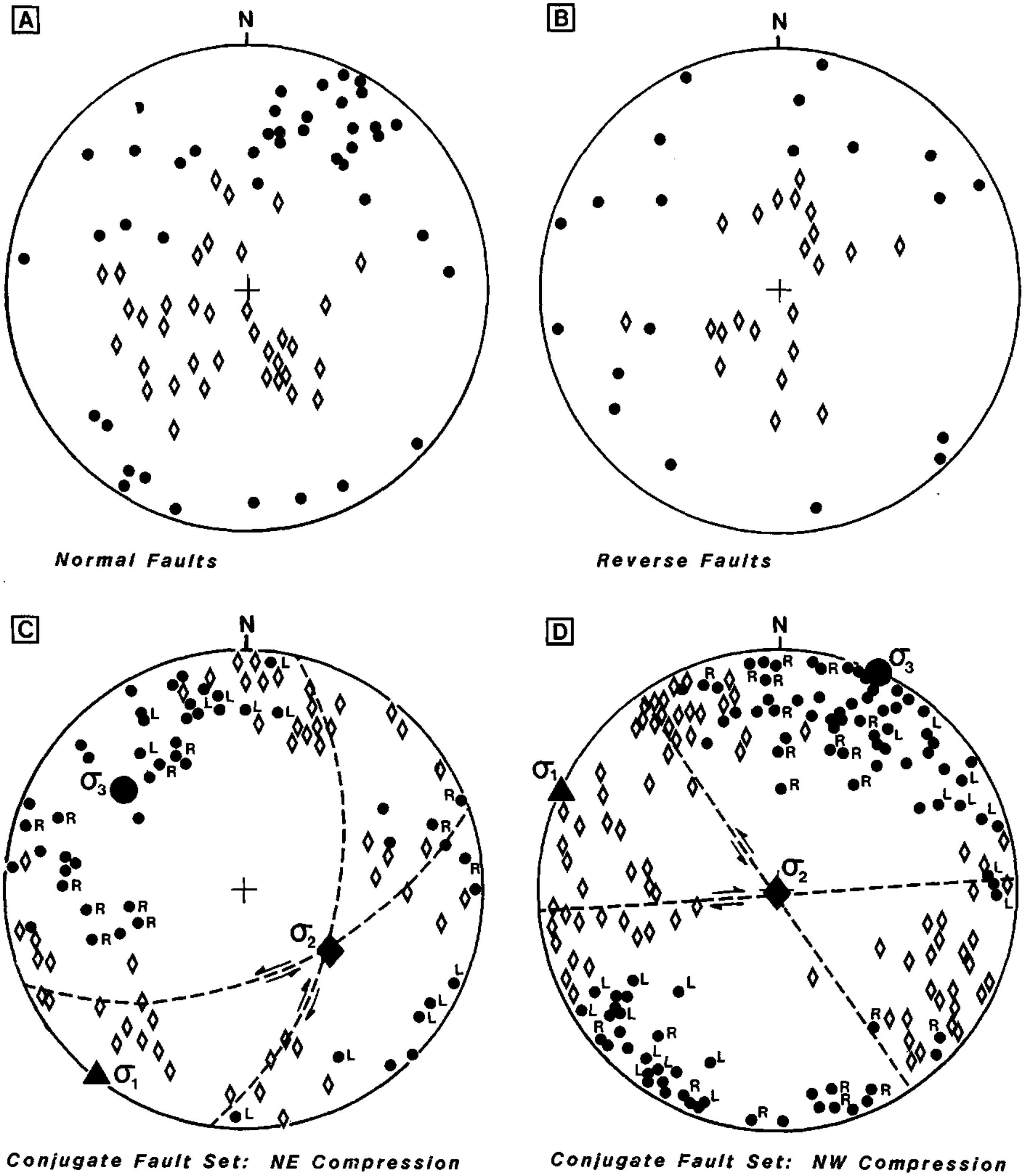


Figure 5. Equal-area lower-hemisphere projections of normal faults (A), reverse faults (B), high-angle strike-slip faults compatible with NE compression (C), and high-angle strike slip faults compatible with NW compression (D): filled circles = poles to fault planes (L and R = left-lateral and right-lateral movement, respectively); open diamonds = slickenside striations; dotted lines = fault planes that best fit striation and fault pole data; large filled triangle = constructed maximum principal compressive stress (1); large filled diamond = constructed intermediate principal stress (2); large filled circle = constructed least principal stress (3).

The data were first divided into three groups: (1) faults showing reverse movement, (2) faults showing normal movement, and (3) the vast majority of the high-angle faults, those exhibiting strike-slip movement. Each group was plotted on a lower-hemisphere, equal-area stereographic projection. Though there is considerable scatter, the normal faults generally strike N70°W and dip steeply toward the southwest (fig. 5a). The poles to the reverse fault planes show no preferred orientation when plotted on a stereonet (fig. 5b).

Two different families of conjugate fractures occur in the study area. In one set, the acute bisector trends northwest-southeast, and in the second set, the acute bisector is oriented northeast-southwest. At several outcrop localities it was observed that the second set (NE) is younger as it cross-cuts and offsets faults of the first set. On the basis of these two sets of conjugate fractures, all strike-slip faults were divided into two groups. The older group (fig. 5d) is interpreted as having formed by northwest-southeast compression, the younger (fig. 5c) by northeast-southwest compression.

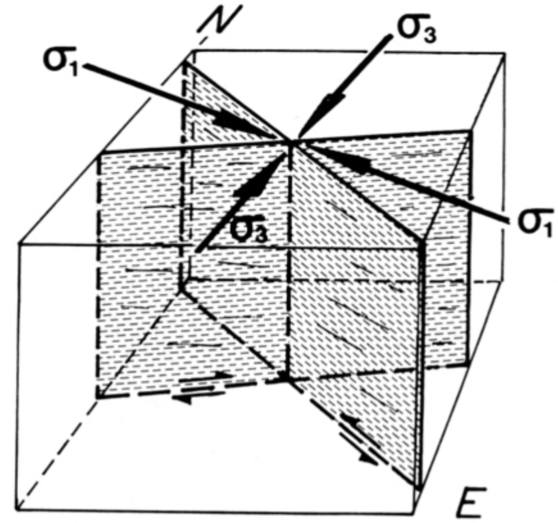
The major map-scale faults that strike approximately east fit the second, younger set best. Slickenside striations on some of these faults indicate that they are, in fact, left lateral strike-slip faults. As was previously mentioned, slickenside striations only record the last movement along the fault. Map relationships (fig. 2) suggest that many of these faults may have experienced major normal movement prior to strike-slip faulting.

CONCLUSIONS

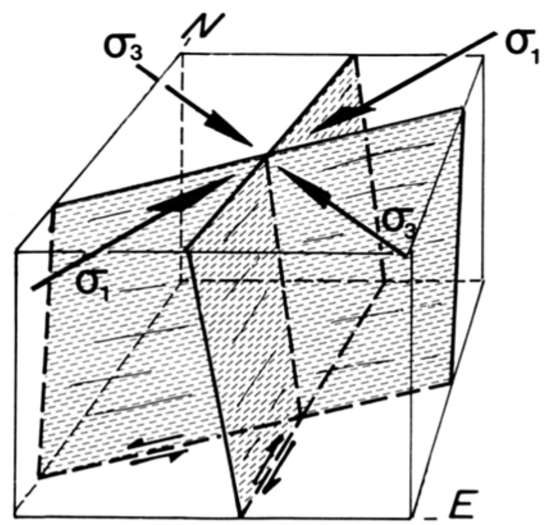
The older high-angle faulting episode (fig. 6a-NW compression) is correlated with the Jurassic to Cretaceous (Brookian) thrusting, while the relationship of the younger one (fig. 6b-NE compression) with a regional stress field is not clear. No specific age can be assigned to the northeast compressional event; the event occurred either in the final stages of the Brookian thrusting episode, or in a later distinct structural event. This compressional event clearly postdates all other structures in the area. If it occurred in the final stages of Brookian thrusting, then a 90-degree reorientation of the principal stress axes during one thrusting event must be envisioned. This scenario is considered highly unlikely. A later distinct structural event, with principal stresses oriented perpendicular to the earlier stress field, is postulated to explain these results.

The sporadically developed normal and reverse faults have no simple relationship with the two postulated stress fields. They may be the result of local adjustments to either of the regional stress regimes.

The third phase axial-plane cleavage strikes northwestward and is sub-vertical throughout the mapped area. This orientation would arise from a northeast-directed compression. Since the majority of the map-scale east-striking high-angle faults appear to have a left-lateral sense of displacement (as deduced from slickenside 'steps') and since the third phase axial-plane cleavage is best developed in the neighborhood of these EW-striking high-angle faults, these two sets of structures may be genetically related, demonstrating that an important NE-SW compressional event has occurred in the Doonerak Window area. In two locations in the study area, both sets of conjugate faults were found in the same outcrop. Cross-cutting relationships in these outcrops showed that the northeast-directed compressional event postdates the northwest-directed event.



A: *Episode 1: NW Compression*



B: *Episode 2: NE Compression*

Figure 6a. Block diagram illustrating stress axes of an earlier faulting episode compatible with NW compression (derived from fault data in fig. 5d): shaded planes = best-fit fault planes of fig. 5d, σ_1 = maximum principal compressive stress, σ_2 = intermediate principal compressive stress, and σ_3 = least principal compressive stress.

Figure 6b. Block diagram illustrating stress axes of a later faulting episode compatible with NE compression (derived from fault data in fig. 5c): shaded planes = best-fit fault planes of fig. 5c, σ_1 = maximum principal compressive stress, σ_2 = intermediate principal compressive stress, and σ_3 = least principal compressive stress.

ACKNOWLEDGEMENTS

We gratefully acknowledge the following companies for providing funds to support this project: Amoco Production Company; Arco Exploration Company; Chevron U.S.A., Inc.; Gulf Oil Exploration and Production Company; Mobil Exploration and Producing Services, Inc.; and The Sohio Petroleum Company. We also acknowledge funds received from the U.S. Department of Energy under contract number DE-AS05-83ER13124.

No reviewers cited.

Draft received 02/12/86.

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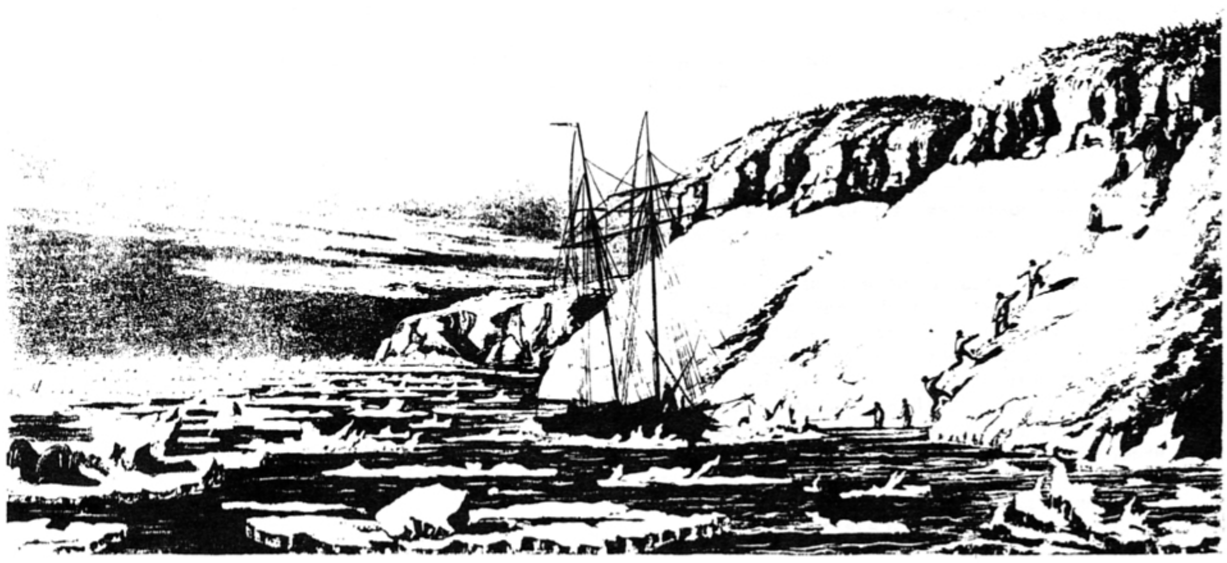

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