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Structural development and kinematic history of ramp-footwall collapse in the Doonerak multiduplex, central Brooks Range, arctic Alaska

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Rice University, 1992
RICE UNIVERSITY

STRUCTURAL DEVELOPMENT AND KINETIC HISTORY OF RAMP-FOOTWALL COLLAPSE IN THE DOONERAK MULTIDUPLEX, CENTRAL BROOKS RANGE, ARCTIC ALASKA

by

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A THESIS SUBMITTED IN PARTIAL FULFILLMENT OF THE REQUIREMENTS FOR THE DEGREE

DOCTOR OF PHILOSOPHY

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ABSTRACT

Structural Development and Kinematic History of  
Ramp-Footwall Collapse in the Doonerak Multiduplex,  
Central Brooks Range, Arctic Alaska  

by  

C. Michael Seidensticker  

The Doonerak multiduplex of the central Brooks Range fold and thrust belt in arctic Alaska developed during footwall collapse beneath the Amawk thrust, which underlies the Endicott Mountains allochthon. The Endicott Mountains allochthon transported Devonian clastic rocks northward over a footwall composed of lower Paleozoic clastic and volcanic rocks of the Apoon assemblage and uppermost Devonian to Carboniferous clastic and carbonate strata. The geometry and kinematic development of the Doonerak multiduplex differ from typical duplex models in that the Doonerak example consists of two stacked duplexes that formed simultaneously. The upper duplex (the Blarney Creek duplex) and the lower duplex (the Apoon duplex) are separated by the Blarney Creek thrust zone, which served both as the floor thrust of the upper duplex and as the roof thrust of the lower duplex. The intervening fault zone between the two stacked duplexes changes character along strike, from that of a sharp tectonic contact to a diffuse zone of distributed shear up to 250 meters thick. In most locations, the fault zone is tens of meters thick and characteristically contains deformed conglomerate. The stratigraphic position of the fault zone was controlled by a thin conglomerate unit which forms the interface between the Apoon assemblage and the overlying clastic and carbonate rocks. The fault zone truncates structures at the base of the upper
duplex and at the top of the lower duplex, locally omitting up to 30 meters of section. Where it is broadest, the Blarney Creek fault zone contains interleaved thin slices of both upper-duplex and lower-duplex lithologies.
ACKNOWLEDGEMENTS

This study is part of a geologic transect across the central Brooks Range which was funded by: the U.S. Department of Energy under grant number DE-AS05-83ER13124; the National Science Foundation under grant number EAR-8517384; and the Rice University Alaska Industrial Associates Program, whose members are 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 Standard Oil Company.

The Alaska Division of Geological and Geophysical Surveys cooperated with helicopter arrangements and other logistical matters. The Alyeska Pipeline Company and the Bureau of Land Management permitted access to helicopter landing sites along the Dalton Highway. Officials of Gates of the Arctic National Park permitted access to the field area, and supported continuation of the study under pressure from other interests to halt it.

Lorraine Wolf and David Stone, both from the Geophysical Institute at the University of Alaska at Fairbanks, coordinated and provided invaluable logistical support.

Jim Murray and Mark K. Thomas provided able assistance and priceless contact with human beings during the field work. They labored much harder and longer, under arduous conditions and without complaint, than should ever be expected of anyone who works without pay. Jeff "Grandma" Huber taught me much of what I needed to know in order to survive a summer in the Brooks Range with body and mind virtually intact.

Lloyd Wenger provided me with free accommodations, regular perspective-maintenance services, and therapeutic comic relief during the prolonged final battle with the dissertation dragons. Thanks, man.
Special thanks go to my wife, Betsy Julian, and to Mom and Dad, for their inexhaustible support and encouragement, and for cheerfully putting up with all of the nonsense.

Finally, I give thanks to my thesis committee: John Oldow, Hans Ave Lallemand, John Anderson and Frank Fisher, for their expert guidance throughout the project.
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INTRODUCTION

The Doonerak window (Brosgé and Reiser, 1971), centrally located in the Brooks Range fold and thrust belt of arctic Alaska (Fig. 1), exposes lower Paleozoic and Carboniferous strata within an erosional breach of a doubly plunging antiform of Devonian clastic rocks (Dutro and others, 1976). The Devonian succession that frames the Doonerak window composes the southern Endicott Mountains allochthon (Mull, 1982). The lower Paleozoic and Carboniferous through Triassic rocks within the Doonerak window have stratigraphic affinities with coeval units underlying the North Slope (Brosgé and others, 1974; Armstrong and others, 1976; Dutro and others, 1976; Armstrong and Mamet, 1978; Mull, 1982; Mull and others, 1987), and for some time have been recognized as a critical link between allochthonous rocks of the fold and thrust belt and autochthonous units underlying the foreland (Fig. 2).

Deciphering the structural significance of the Doonerak window has proved to be more elusive than recognizing its paleogeographic significance. Although early workers identified thrust faults dipping away from both flanks of the east-northeast trending antiform (Brosgé and Reiser, 1971), the relation between the structures on the northern and southern flanks of the fold was debated. Clear thrust relations were identified along the northeastern flank, where Devonian clastic rocks structurally overlie Carboniferous carbonate strata (Brosgé and Reiser, 1971). Although south-dipping thrusts were recognized along the southern flank of the window, the nature of the contact between lower Paleozoic and Devonian clastic rocks was more enigmatic and was thought to be depositional (Brosgé and Reiser, 1971; Mull, 1982). It was unclear whether the thrusts recognized on the northern and southern flanks of the Doonerak window were parts of a single folded fault or separate structures with unrelated kinematic histories (Dutro and others, 1976).
Figure 1. Generalized geologic map of the central Brooks Range, showing major allochthons (after Oldow and others, 1987a). Exposure of the Doonerak window results from erosion through the crest of a doubly plunging anticline that folds the overlying Endicott Mountains allochthon. AT = Amawk thrust; BCT = Blarney Creek thrust; ET = Eekayruk thrust; DW = Doonerak window; EMA = Endicott Mountains allochthon
Figure 2. Stratigraphic relationships between the Doonerak window and adjacent structural packages. Stratigraphic units exposed in the Doonerak window are equivalent to those encountered in wells on the autochthonous North Slope. The North Slope stratigraphic column is represented by well-logs, showing Spontaneous Potential on the left and Resistivity on the right. The stratigraphic columns of the Doonerak window and overlying Endicott Mountains allochthon are very similar for the younger part of the columns, down to the Kayak Shale, below which the columns are markedly different. Lithologically controlled zones of decollement are indicated by arrows, labelled "d." In the Doonerak window, the Amawk thrust is usually located at the top of the Lisburne Group, although the thrust occasionally steps up into the Permo-Triassic strata. The Blarney Creek duplex is constructed with horses containing predominantly Kayak Shale and Lisburne Group, the Apoon duplex is constructed with horses derived predominantly from the Apoon assemblage, and the detached boundary layer separating the Blarney Creek and Apoon duplexes is composed predominantly of Kekikktuk Conglomerate (modified from Mull and others, 1987).
Mull (1982) recognized the tectonic significance of the Amawk thrust fault on the northern flank of the Doonerak window as the basal decollement of the far-travelled Endicott Mountains allochthon. The Endicott Mountains allochthon was interpreted as having been displaced tens to possibly hundreds of kilometers to the north (Mull and others, 1987; Oldow and others, 1987a). The structural significance of the underlying Carboniferous and lower Paleozoic rocks has been more controversial, however. The rocks within the Doonerak window were generally thought to be autochthonous or paraautochthonous relative to Brookian contractional structures (Dutro and others, 1976), and it was suggested that the structurally high position of these "basement" strata may be a result of isostatic uplift (Mull, 1982).

Subsequent mapping documented a south-dipping thrust fault between lower Paleozoic and Devonian strata on the southern margin of the Doonerak window (Julian and others, 1984; Oldow and others, 1984; Mull and others, 1987). Detailed work established the structural continuity of the basal decollement of the Endicott Mountains allochthon, the Amawk thrust, around the eastern closure of the Doonerak window (Fig. 3) with only minor offset along a later, out-of-sequence thrust fault (Phelps, 1987, 1993; Julian, 1989, 1993a) here called the Eekayruk thrust. These relations were pivotal in recognizing the duplex origin of the Doonerak window. Structural analysis (Julian, 1989, 1993a; Phelps, 1987, 1993) and construction of regional balanced cross sections (Oldow and others, 1987a) demonstrated that the Doonerak duplex formed during late-stage imbrication beneath the Endicott Mountains allochthon.

Careful assessment of the structure and kinematics of the Doonerak duplex indicates a complex history of footwall collapse during northward displacement of the Endicott Mountains allochthon above the Amawk thrust. The Endicott
Figure 3. Simplified geologic map of the eastern Doonerak window and surrounding area. Data compiled from: this study, Phelps (1987), Oldow and others (1987a), Julian (1989), and Boler (1989). Cross section X-X′ is shown in Fig. 4. AT = Amawk thrust; BCT = Blarney Creek thrust; ET = Eekayruk thrust; $H_1$ = Apoon duplex Horse 1; $H_2$ = Apoon duplex Horse 2; $H_3$ = Apoon duplex Horse 3; $H_4$ = Apoon duplex Horse 4.
Mountains allochthon behaved as a relatively coherent upper-plate unit during formation of the duplex, with the Amawk thrust serving as the roof thrust during imbrication of the underlying Devono-Carboniferous and lower Paleozoic rocks. Footwall shortening in the Doonerak duplex was accommodated by two subsidiary, stacked duplexes (Fig. 4). An upper duplex is structurally separated from a lower duplex by a shear zone named the Blarney Creek thrust (Seidensticker and others, 1987a). The Blarney Creek thrust is a broad zone of shear that served both as the floor thrust of the overlying duplex composed of uppermost Devonian to Carboniferous rocks, and simultaneously as the roof thrust that accommodated duplex development within the structurally deeper lower Paleozoic strata. A remarkable feature of this fault zone is that it nucleated around a thin (5 to 20 m thick) conglomerate unit located at the pre-tectonic depositional contact between Devono-Carboniferous and lower Paleozoic rocks. The floor thrust of the overlying duplex developed immediately above the conglomerate unit, whereas the roof thrust of the underlying duplex developed immediately below it. The conglomerate unit behaved as a boundary layer between, and was itself shortened contemporaneously with, the duplexes above and below. With few exceptions, rocks of the conglomerate boundary layer were not incorporated in the horses of either duplex, but rather "floated" in the intervening detachment zone.

The focus of this work is to document the kinematic evolution of footwall collapse in the Doonerak duplex, and to assess its implications for duplex formation in general. Emphasis is placed on the development of the stacked footwall duplexes and on the kinematic significance of the boundary layer shear zone (Blarney Creek thrust) that separates them. Conceptual models for the development of duplex structures, discussed below, are evolving rapidly, and increasing attention is being
Figure 4. Cross section through the Doonerak window (see Fig. 3 for location and scale). Beneath the antclinally folded Amawk thrust and overlying Endicott Mountains allochthon, the Doonerak window contains two stacked duplexes, the Blarney Creek duplex and the Apoon duplex, which together compose the Doonerak multiduplex. The roof thrust of the Blarney Creek duplex is the Amawk thrust. The floor thrust of the Blarney Creek duplex is the Blarney Creek thrust, which is also the roof thrust of the underlying Apoon duplex in the footwall of the out-of-sequence thrust. In the hanging wall of the out-of-sequence thrust, the Blarney Creek duplex is absent and the roof thrust of the Apoon duplex is the Amawk thrust. SA = Skajit allochthon; EMA = Endicott Mountains allochthon; BCD = Blarney Creek duplex; AD = Apoon duplex.
paid to nonsequential (out-of-sequence) progressive deformation and the formation of complex geometries.

**DUPLEX KINEMATICS**

Duplex structures are common architectural features of fold and thrust belts that have been recognized in areas throughout the world (e.g., Willis, 1902; Peach and others, 1907; McIntyre, 1954; Bally and others, 1966; Dahlstrom, 1970; Boyer, 1978; Elliott and Johnson, 1980; Bell, 1983; McClay and Coward, 1981; Pfiffner, 1981; Price, 1981; Boyer and Elliott, 1982; Cooper and others, 1983; Bosworth, 1984; Nickelsen, 1986; Banks and Warburton, 1986; Bowler, 1987; Fermor and Price, 1987; Schirmer, 1988; Yin and others, 1989; Wallace and Hanks, 1990; Skuce and others, 1992). The term "duplex" describes a plexus of imbricate thrust faults within which the trajectories of individual faults emerge from a common floor thrust and are asymptotic upward into a common roof thrust. Boyer and Elliott (1982) used balanced graphical techniques to model duplex formation as the progressive collapse of a thrust-ramp footwall (Fig. 5A). As a duplex develops, slip is transferred from the floor thrust to the roof thrust via a system of subsidiary ramping thrust faults. The ramping thrusts create imbricate horses that are plucked sequentially, in the direction of tectonic transport, from the footwall. Slip transfer and creation of additional horses cause structural thickening; duplex growth is accompanied by folding of the overriding thrust sheet and addition of mass to the moving thrust complex (Boyer and Elliott, 1982).

Using the method of graphical forward models, several investigators have simulated a large variety of theoretical duplex structures arising from variations on the basic scheme proposed by Boyer and Elliott (1982). Variables include ramp height (horse thickness), ramp angle, spacing between horse-bounding thrusts (horse
Figure 5. Kinematic models for duplex development.

A: Sequential model for duplex development, after Boyer and Elliott (1982). The duplex grows by sequential plucking of horses from the footwall of a ramping thrust sheet, as the location of the ramp migrates forward through time. The roof and floor thrusts merge into a single thrust fault both forward and hindward of the collection of horses that compose the duplex; addition of horses to the growing duplex causes structural thickening of the allochthonous mass and folding of the overriding thrust sheet.

B: An alternative model for duplex development, after Yin and others (1989). Two separate duplexes share the same floor thrust, but have separate roof thrusts at different structural levels. The roof and floor thrusts persist as distinct and separate faults over distances much greater than the lengths of the individual duplexes. At a later stage, the roof and floor thrusts become kinematically linked by the development of subsidiary thrusts that connect the floor with the roof.

C: Model for multiduplex development, after Fermor and Price (1987). The multiduplex consists of five stratigraphically distinct horses which collectively form a large duplex structure. Each of the stratigraphically distinct horses is in itself a smaller-scale duplex structure, some of which may have developed simultaneously.
length), and the amount of displacement of individual horses (Butler, 1982a; Suppe, 1983; Boyer, 1986a; Mitra, 1986, 1987; Mitra and Boyer, 1986; Banks and Warburton, 1986; Marshak, 1987).

Recognition of the geometric features that define a duplex, however, does not necessarily imply that the structure developed in the sequential manner described by Boyer and Elliott (1982). Boyer (1986b) gave examples suggesting that some duplexes may have developed by simultaneous, rather than sequential, movement on multiple thrust faults. Other workers (Fermor and Price, 1987; Woodward and others, 1989; Yin and others, 1989) have also shown that the fundamental geometry of a duplex can arise through other kinematic paths quite different than the one originally proposed by Boyer and Elliott (1982).

Yin and others (1989) described two related duplexes separated by 20 km, measured in the direction of tectonic transport (Fig. 5B). The duplexes share a common floor thrust (the Lewis thrust of the northern U.S. Rocky Mountains) but have different roof thrusts. The roof thrusts persist as distinct and separate faults over distances much greater than the 2 to 3 km lengths of the individual duplexes. Yin and others (1989) proposed that the roof thrusts operated synchronously with but kinematically independent of the floor thrust for some time prior to the development of any duplex structures. Duplex formation is visualized to be a late-stage phenomenon, following initial displacement on the independent thrust systems. Yin and others (1989) speculate that the subsidiary imbricate faults kinematically linking the floor and roof thrusts may have developed in a fashion analogous to the development of Riedel P shears.

In addition to complex kinematic histories, duplex morphology can also be quite complex. Fermor and Price (1987) used the term "multiduplex" to describe a structure along the base of the Lewis thrust in the southern Canadian Rocky
Mountains (Fig. 5C). Their multiduplex consists of five or more stratigraphically distinct but structurally overlapping duplexes that occur together as nested, lenticular stacks of imbricated, sigmoidal thrust slices. Collectively, the entire complex of lenticular stacks constitutes a large duplex structure within which each of the individual stacks forms a small duplex structure. Fermor and Price (1987) indicated that even though certain aspects of the kinematic history of the structurally complicated multiduplex are not fully understood, some of the individual duplex structures within the multiduplex may have formed concurrently.

Based on a detailed structural and kinematic analysis of the eastern Doonerak duplex, the synchronous development of multiple levels of detachment during duplex formation can be documented. In fact, the Doonerak duplex can be described as a multiduplex consisting of two stacked, subsidiary duplexes that simultaneously accommodated footwall collapse beneath the ramping Amawk thrust. Displacements that occurred on bounding fault surfaces between the two duplexes resulted in truncation of imbricate horses in both duplexes. The Doonerak multiduplex is an excellent example of nonsequential development of contractional structures, which may represent a more prevalent scheme of shortening than that generally attributed to fold and thrust belts.

**STRUCTURAL FRAMEWORK OF THE DOONERAK MULTIDUPEX**

Rocks in and around the Doonerak window are complexly deformed and compose two fundamental structural units relative to the Amawk thrust: an upper plate, or hanging-wall assemblage, consisting of the Endicott Mountains allochthon and a lower plate, or footwall assemblage, composed of Devonian-Carboniferous and/or lower Paleozoic rocks (Figs. 3 and 4). This fundamental structural scheme is modified by a post-duplex thrust (the Eekayruk thrust) and by later high-angle
faults. The Eekayruk thrust is out-of-sequence with respect to the imbrication history of this part of the Brooks Range fold and thrust belt (Phelps, 1987, 1993), and it juxtaposes different parts of the footwall and hanging-wall assemblages of the Doonerak window (Figs. 3 and 4). On the north, below the Eekayruk thrust, the Doonerak multiduplex is composed of both lower Paleozoic and Devonian-Carboniferous rocks, whereas to the south, above the Eekayruk thrust, the duplex conspicuously lacks the Devonian-Carboniferous rocks, and the lower Paleozoic rocks are directly overlain by the Endicott Mountains allochthon. For further details on the kinematic history of the Eekayruk thrust, the reader is referred to Phelps (1993).

Younger high-angle faults truncate thrust faults on the north flank of the Doonerak window and form an east-west trending belt up to 5 km wide (Fig. 3). Individual faults within the belt have trace lengths of up to 10 km and occasionally anastomose with other fault strands along strike. In other cases, individual fault strands are discontinuous along strike and step both left and right in poorly defined en echelon patterns. Vertical displacement on the faults typically is on the order of 300 m or less. The greatest throw observed does not exceed 1.5 km. Left-lateral motion is documented on several of the faults (Phelps and others, 1987; Phelps, 1993), which are decorated with subhorizontal slickenside lineations and fibrous vein minerals.

General aspects of the stratigraphy and the structural history of the hanging-wall and footwall assemblages of the Doonerak multiduplex are discussed separately below. Detailed discussion of the stratigraphy and structure is focused on the footwall assemblage, the deformation of which is the primary concern of this study.
Hanging-Wall Assemblage: Endicott Mountains Allochthon

The Endicott Mountains allochthon constitutes the hanging-wall assemblage of the Amawk thrust. Detailed stratigraphic and structural analysis of this assemblage is beyond the scope of this study and the reader is referred to Phelps (1993) and Handschy (1993a, 1993b) for details. Below, the general structural and stratigraphic characteristics of the Endicott Mountains allochthon are summarized in light of their significance to deformation in the footwall.

STRATIGRAPHY

In the vicinity of the Doonerak window, the Endicott Mountains allochthon is composed of Devonian clastic rocks, whereas, to the north of Atigun Pass (Fig. 1), the Devonian clastic succession is overlain by Carboniferous and younger clastic and carbonate rocks. The Endicott Mountains allochthon and its footwall assemblage exposed in the Doonerak window share several stratigraphic units (Fig. 2). Nevertheless, the two successions are easily differentiated because of substantial differences in lithology, thickness, and depositional setting of the units within the footwall and hanging-wall assemblages.

The Endicott Mountains allochthon is dominated by the clastic and carbonate rocks of the Endicott and Lisburne Groups (Mull, 1982; Handschy, 1988, 1993a). In ascending stratigraphic order, the Upper Devonian and Lower Mississippian Endicott Group is composed of the Hunt Fork Shale, the Kanayut Conglomerate, and the Kayak Shale (Tailleur and others, 1967). Contacts between all three units are thought to be conformable, but in many cases the contacts were strongly sheared during Brookian tectonism (Handschy, 1988, 1993a). Depositionally underlying the Hunt Fork Shale is the Middle(?) to lower Upper Devonian Beaucoup Formation, which is composed of fine-grained calcareous and
siliciclastic rocks (Bowsher and Dutro, 1957; Brosgé and others, 1962; Chapman and others, 1964; Nilsen, 1981; Phelps, 1993; Handschy, 1988, 1993a). Conformably overlying the Kayak Shale are Lower Mississippian through Lower Pennsylvanian carbonate rocks of the Lisburne Group (Bowsher and Dutro, 1957).

The lithology and thickness of rocks composing the Endicott Group in the hanging-wall and footwall assemblages of the Amawk thrust differ greatly. In the hanging wall, the Endicott Group is composed of Hunt Fork Shale, Kanayut Conglomerate, and Kayak Shale, which have an aggregate thickness of greater than 8 km (Handschy, 1988, 1993a). In the footwall assemblage, however, the Endicott Group is composed of the Kekiktuk Conglomerate and Kayak Shale, which have a combined thickness of about 1.1 km. Depositionally, the Kayak Shale in both assemblages represents the same shallow marine environment. The major difference in depositional setting of the Endicott Group in the footwall and the hanging wall lies in comparison of the Kekiktuk Conglomerate with the Kanayut Conglomerate and underlying Hunt Fork Shale. The upper Upper Devonian to Mississippian Kekiktuk Conglomerate achieves a maximum thickness of about 10 to 20 m and is interpreted to be a transgressive beach deposit (Handschy, 1988, 1993a). In dramatic contrast are the Upper Devonian through Lower Mississippian (?) fluvial-deltaic rocks of the Hunt Fork Shale and Kanayut Conglomerate (Tailleur and others, 1967; Nilsen, 1981; Nilsen and Moore, 1984; Handschy, 1988, 1993a). From north to south in the Endicott Mountains allochthon, the Kanayut Conglomerate ranges from 2.6 to 1.0 km thick and consists of interbedded conglomerate and sandstone beds deposited primarily in braided stream environments (Nilsen and Moore, 1984; Handschy, 1988, 1993a). The Hunt Fork Shale gradationally underlies the Kanayut Conglomerate and has a structural thickness of about 6 km. Internal deformation obscures the original stratigraphic
thickness of the Hunt Fork, but lithofacies analysis indicates deposition in prodelta slope and shelf environments which grade vertically into the overlying Kanayut (Handschy, 1988, 1993a).

The difference between exposures of the Lisburne Group carbonates in the hanging-wall and footwall assemblages is subtle in comparison to the differences in the Endicott Group. In both assemblages, the Lisburne is composed of a distinctive, cliff-forming limestone that generally weathers light gray and conformably overlies the Kayak Shale. The depositional setting of the Lower Mississippian to Lower Pennsylvanian carbonates differs, however, between the two assemblages. The Lisburne Group of the Endicott Mountains allochthon was deposited in more distal, open-marine conditions than coeval rocks of the footwall assemblage (Armstrong and others, 1976). Carbonate rocks of the Lisburne Group in the footwall assemblage are a more proximal facies and bear strong similarities with the Lisburne of the North Slope encountered in wells and exposed in the northeastern Brooks Range (Armstrong and others, 1976).

The Middle(?) to Upper Devonian Beacoup Formation (Tailleur and others, 1967; Dutro and others, 1979) has a structural thickness of about 1.5 km in the southern Endicott Mountains allochthon (Phelps, 1993) and is not found within the footwall assemblage. The Beacoup Formation is a sequence of interlayered shale, calcareous shale, sandstone, conglomerate, volcaniclastic rocks, and limestone reef deposits that underlies the Hunt Fork Shale, possibly disconformably (Phelps, 1992; Handschy, 1988, 1993a). The bottom of the Beacoup Formation in the Doonerak window region is not exposed because it is cut out by the Amawk thrust. On the south flank of the Doonerak window, the Beacoup structurally overlies lower Paleozoic rocks of the footwall assemblage. Tracing the structural contact around the eastern closure of the window to the north, the Beacoup rests on
Carboniferous rocks of the footwall assemblage and thins from its maximum thickness of 1.5 km in the south to less than a few hundred meters. To the west, along the north flank of the window, the Beaucoup Formation is completely cut out by the Amawk thrust.

**STRUCTURE**

As discussed in detail by Handschy (1988, 1993b), the Endicott Mountains allochthon underlies most of the frontal part of the Brooks Range fold and thrust belt and consists of an east-west striking stack of north-directed thrust sheets (Fig. 1). Substantial spatial variability exists in the structural character of the allochthon. In the north, it is composed of numerous imbricates, whereas in the south, it is composed of a single thrust nappe. The thrust nappe composing the southern Endicott Mountains allochthon is about 8 km thick above the northern flank of the Doonerak multiduplex (Handschy, 1988, 1993b). Nappe thickness decreases to the south where the Endicott Mountains allochthon is cut out by the basal thrust of the overlying Skajit allochthon (see Oldow and others, 1993a, 1993b).

Three generations of structures are recognized in the basal part of the Endicott Mountains allochthon exposed around the eastern Doonerak window (Phelps, 1987, 1993; Handschy, 1988, 1993b). The relative ages of the structures are established on the basis of cross-cutting relationships, and they are designated $D_1$, $D_2$ and $D_3$ in order of decreasing age.

Results of a detailed investigation of the polyphase structural history of the Endicott Mountains allochthon are presented by Handschy (1988, 1993b), who documents substantial spatial variation in the development of mesoscopic and map-scale structures. The structural variability is systematic and is the product of vertical and horizontal strain gradients formed during progressive north-directed thrusting.
In the vicinity of the Doonerak window, where the deepest parts of the Endicott Mountains allochthon are exposed, \( D_1 \) structures can be further subdivided into earlier and later phases (\( D_{1a} \) and \( D_{1b} \) of Handschy, 1988, 1993b). Although it is critical to a complete understanding of the progressive deformation of the allochthon, no differentiation is made between earlier and later \( D_1 \) structures in the following discussion.

**First-Generation Structures (\( D_1 \))**

Within the Endicott Mountains allochthon around the eastern Doonerak window, first-generation structures (\( D_1 \)) are most commonly expressed by a cleavage (\( S_1 \)) that is axial planar to tight to isoclinal folds of bedding (\( S_0 \)). Small first-phase folds are rarely preserved and generally are rootless structures, commonly with a sheath-fold morphology. \( D_1 \) fold axes generally lie in the down-dip orientation of \( S_1 \) cleavage (Fig. 6). In fine-grained clastic units, \( S_1 \) cleavage is penetrative, but in coarse clastic rocks and carbonate interbeds, \( S_1 \) cleavage is spaced and/or hackly, and commonly is difficult to recognize.

The orientation of \( S_1 \) is usually subparallel (within 10°) with the underlying Amawk thrust. On the south flank of the window, the Amawk thrust and \( S_1 \) in the hanging-wall dip steeply southeast, whereas north of the window both the thrust and the first cleavage dip gently north (Fig. 6).

**Second-Generation Structures (\( D_2 \))**

Second-generation structures (\( D_2 \)) are expressed by gentle to open asymmetric folds and kink bands of the \( S_1 \) cleavage. The kink bands and asymmetric \( D_2 \) folds are preferentially developed in fine-grained lithologies and have half-wavelengths ranging from millimeters to tens of meters. The northeasterly trending \( D_2 \) folds and kinks typically have subhorizontal fold axes
Figure 6. Polyphase structural data for the eastern Doonerak window area, shown in lower-hemisphere, equal-area projections. For $S_0$, filled circles represent poles to bedding. For $D_1$, $D_2$ and $D_3$, filled circles represent poles to cleavage and axial planes and open circles represent fold axes.
BLARNEY CREEK DUPLEX

APOON DUPLEX

SOUTHERN ENDICOTT MOUNTAINS ALLOCHTHON
(Fig. 6). D2 axial planes generally dip moderately to steeply to the northwest, but occasional southeast dips are observed and apparently are related to rarely observed box folds. The D2 folds and kinks commonly have a crenulation cleavage parallel to the axial plane.

Unlike D1 structures, whose orientations vary from the north to the south side of the Doonerak window, D2 structures within the Endicott Mountains allochthon maintain the same orientation throughout. The D2 folds and crenulation cleavage predominantly dip to the northwest both in the gently north-dipping northern exposure of the allochthon and also in the steeply south-dipping exposure on the southern side of the window. The geometry of D2 structures is coincident with the antiformal structure of the Doonerak window, and the development of D2 is thought to be related to duplex development (Julian, 1993a; Avé Lallemand and Oldow, 1993).

Third-Generation Structures (D3)

Third-generation structures (D3) are a northwest-striking, subvertical crenulation cleavage that overprints both S1 and S2 foliations. Rare, gentle D3 folds are observed and they consistently have subvertical, northwest striking axial planes. Fold axes vary according to the local orientation of S0, S1, and S2 (Fig. 6). Like D2 structures, D3 structures have the same orientation on both flanks of the Doonerak window.

Footwall Assemblage: Doonerak Multiduplex

The Devonian-Carboniferous and lower Paleozoic rocks of the footwall assemblage compose two stacked duplexes, which in descending structural order are the Blarney Creek duplex and the Apoon duplex (Figs. 3 and 4). These footwall duplexes, which together compose the Doonerak multiduplex, are separated by the
Blarney Creek thrust. The Blarney Creek duplex has a structural thickness of 180 to 800 m and, with the exception of thin, volumetrically insignificant slivers of Permian and Triassic clastic rocks and minor slices of Apoon assemblage rocks, is composed of Carboniferous clastic and carbonate strata. Imbricate faults within the duplex merge upward into the Aonak thrust and downward into the Blarney Creek thrust, from which the duplex derives its name. The underlying Apoon duplex is composed almost entirely of lower Paleozoic clastic and volcanic rocks of the Apoon assemblage (Julian, 1989, 1993b) but does also contain minor exposures of Devoniano-Carboniferous clastic rocks (Kekiktuk Conglomerate and Kayak Shale). The Blarney Creek thrust serves as the roof thrust of the lower duplex, but its floor thrust is not exposed. The thickness of the Apoon duplex is uncertain but, based on regional balanced cross sections (Oldow and others, 1987a) and wide-angle seismic reflection data (Levander and others, 1993), is on the order of 25 km. Only about 3 km of structural section of the Apoon duplex are exposed in the Doonerak window (Julian, 1989, 1993b).

**STRATIGRAPHY**

Although rocks within the two duplexes are highly deformed, they preserve their original, pre-tectonic stratigraphic order. The Apoon assemblage is overlain by a thin section of Devonian-Carboniferous clastic rocks comprising the Endicott Group (Kekiktuk Conglomerate and Kayak Shale), which in turn is overlain by carbonate rocks of the Carboniferous Lisburne Group (Fig. 2). The stratigraphic succession is capped locally by minor remnants of fine-grained clastic rocks of the Permo-Triassic Sadlerochit Group, limestone and shale of the Triassic Shublik Formation, and the Triassic Karen Creek Sandstone. The lithologic units of the footwall assemblage are described below in ascending stratigraphic order.
Apon Assemblage

Lower Paleozoic rocks of the Apon assemblage, composed of volcanic, volcanogenic and fine-grained clastic rocks (Julian, 1989, 1993b), dominate the exposures of the Doonerak window. The rocks reside in four thrust-bound slices (Figs. 3 and 4), and although they differ in lithology, they are thought to be structurally telescoped facies of a largely coeval assemblage (Julian, 1989, 1993b). Julian (1989, 1993b) palinspastically restores the rocks as a series of east-west trending sedimentary environments progressing from a northern volcanic arc, southward to a proximal volcanioclastic apron, to a facies of mixed volcanogenic and fine-grained, phyllitic clastic rocks which pass southward into a distal fine-grained clastic succession.

Age constraints for the Apon assemblage are sparse and yield a wide range of dates. Conventional K/Ar and ⁴⁰Ar/³⁹Ar dates on mafic dikes containing hornblende (Dutro and others, 1976) define two clusters of ages, one at about 470 Ma (Middle Ordovician) and the other at about 380 Ma (Middle Devonian). Dutro and others (1976) attribute the two age clusters to different mafic intrusive events. Biostratigraphic age control is supplied by a few fossil assemblages found within the Apon assemblage. Dutro and others (1984) reported Middle Cambrian trilobites, brachiopods, and paraconodonts from a locality at the far western end of the Doonerak window. The trilobites have taxonomic affinities with Siberian forms, similar to other trilobites found in the central Brooks Range (Dutro and others, 1984). Ordovician to Early Silurian graptolites have been recovered from Apon assemblage exposures near the northwestern flank of the Doonerak window (Moore and Churkin, 1984). One graptolite location, near the summit of Amawk Mountain, is reported within the study area (Churkin, written communication, 1984) and indicates an Ordovician to Silurian age.
Kekiktuk Conglomerate

The Kekiktuk Conglomerate represents the basal unit of the Devonian-Carboniferous Endicott Group (Brosge and others, 1962) in the footwall assemblage. Exposures of the Kekiktuk are concentrated along the northeastern flank of the Doonerak window at the contact between the Apoon duplex and the Blarney Creek duplex. The age of the formation is poorly constrained. The only fossils that have been found are a few poorly preserved plant fragments of unknown age from a location in the northeastern Brooks Range (Brosge and others, 1962). Based on its stratigraphic position conformably beneath the Lower Mississippian Kayak Shale, the conglomerate is assigned an age of Late (?) Devonian or Early Mississippian (Brosge and others, 1962).

The Kekiktuk is a lithologically distinctive unit that consists of light gray, yellowish, or yellow-green weathering chert-pebble conglomerate, grit, and sandstone interbedded with siltstone and shale. Most of the interbeds are lenticular and usually cannot be traced laterally in outcrop for more than a few meters. In the Doonerak window, the Kekiktuk Conglomerate typically is about 5 to 10 m thick, but the thickness is highly variable, increasing up to 100 m in some places and decreasing to zero in others. Conglomerate clasts typically are tectonically flattened and lie parallel to the $S_1$ cleavage that is penetratively developed in fine-grained lithologies of the unit. Conglomerate interbeds within the Kekiktuk achieve thicknesses of 5 m but generally are 2 m or less. The conglomerates generally are clast-supported and massive, but some display planar to trough cross-stratification. The subrounded to rounded clasts are almost entirely light gray to dark gray to black chert, with minor amounts of polycrystalline quartz clasts, and rare, dark gray to black mudstone clasts. A wide range of clast sizes is found with a maximum of about 5 cm. The conglomerate matrix consists of subrounded to rounded quartz and
chert grains of sand to silt size. Sandstone and siltstone interbeds are massive, with thickness of up to 5 m but more typically of 2 m or less. The sand and silt fraction consists of subrounded to rounded, moderately well-sorted to well-sorted quartz grains with subordinate chert. Frequently, the stratigraphically lowest unit of the Kekiktuk is a yellow-green phyllite. Most of the Kekiktuk Conglomerate is interpreted as having been deposited in a south-flowing fluvial system dominated by braided streams (Nilsen, 1981). The upper part of the unit is probably a transgressive beach deposit (Armstrong and Mamet, 1978; Handschy, 1988, 1993a).

The Kekiktuk Conglomerate is probably correlative, at least in part, with the upper Kanayut Conglomerate (Bowsher and Dutro, 1957) exposed in the Endicott Mountains allochthon. Both units are interpreted to be mostly fluvial deposits and both are conformably overlain by the Mississippian Kayak Shale. They differ greatly in their thicknesses: regionally the Kekiktuk ranges from 5 to 100 m thick, whereas the Kanayut ranges from 1.0 to 2.6 km thick. They also differ in the nature of underlying units, with the Kanayut conformably overlying the Devonian Hunt Fork Shale in the Endicott Mountains allochthon and with the Kekiktuk resting on the lower Paleozoic Apoon assemblage in the Doonerak window.

Exposures of the Kekiktuk Conglomerate tend to be poor and discontinuous. The formation is thin and frequently is buried beneath talus derived from the overlying units. These conditions make it difficult to find locations where either the upper or lower contact of the Kekiktuk is clearly exposed. Nevertheless, the Kekiktuk demonstrably overlies all four members of the Apoon assemblage and in some instances the contact is depositional. As discussed below in some detail, dark gray phyllite of the Apoon assemblage exposed on the south flank of Falsoola Mountain is interbedded with basal gray-green and yellow-green phyllite of the Kekiktuk on the scale of centimeters to a meter. Elsewhere, in Kuyuktuvuk and
Trembley Creeks, Phelps (1987, 1993) describes similar gradational contacts between the basal Kekiktuk and fine-grained clastic rocks of the underlying Apoon. In a location just south of Amawk Creek, basal gray-green phyllite of the Kekiktuk is in depositional contact with volcaniclastic sandstone and conglomerate of the Apoon. In most cases, however, the contact between the Kekiktuk and the clastic and volcanic rocks of the Apoon assemblage is tectonic.

Kayak Shale

Gradationally overlying the Kekiktuk Conglomerate is the Mississippian Kayak Shale (Bowsher and Dutro, 1957; Armstrong and others, 1976). The Kayak Shale is found in all three structural units exposed in the Doonerak window area: it occurs within the Endicott Mountains allochthon of the hanging-wall assemblage, and within both the Apoon and Blarney Creek duplexes of the footwall assemblage.

At the base, the Kayak is composed of a black siltstone and/or very fine-grained sandstone unit up to 15 m thick. The basal unit is interpreted to represent intertidal environments (Nilsen, 1981). This basal unit is overlain abruptly by noncalcareous, black marine shale containing minor siltstone interbeds. The black shale constitutes the bulk of the formation and typically contains one or more distinctive interbeds of red-weathering crinoidal packstone or wackestone ranging from 20 cm to 1 m thick.

The Kayak Shale is a mechanically weak horizon that provided an important decoupling surface during Brookian tectonism. As a result, the thickness of the unit varies dramatically from very thin or absent in some places to a maximum of about 150 m. Generally, the Kayak thickness ranges from 50 to 100 m.
Lisburne Group

The carbonate rocks of the Lisburne Group (Bowsher and Dutro, 1957) conformably overlie the Kayak Shale. The Upper Mississippian to Lower Pennsylvanian Lisburne Group is composed of carbonate platform deposits (Armstrong and others, 1976) that achieve a stratigraphic thickness of about 300 m in the Doonerak window. This distinctive unit is an important regional stratigraphic marker consisting of light gray, usually massive, cliff-forming limestone. The Lisburne is abundantly fossiliferous and contains corals, crinoids, brachiopods, and bryozoans.

Sadlerochit Group, Shublik Formation, and Karen Creek Sandstone

In foreland exposures, the Sadlerochit Group typically disconformably overlies the Lisburne Group (Detterman and others, 1975; Crowder, 1990). In the Doonerak window, the Sadlerochit Group is sparsely exposed, and only the basal Permian Echooka Formation (the lowest unit of the Sadlerochit Group) is preserved in a few outcrops. One small exposure is located on the north wall of Amawk Creek where the Echooka is about 15 m thick and is composed of reddish-brown weathering calcareous siltstone that contains Permian (?) brachiopods (Armstrong and others, 1976). The Echooka Formation overlies carbonate rocks of the Lisburne Group and is structurally decapitated by an intra-duplex thrust that places the Kayak Shale above the Permian rocks. At Bombardment Creek (about 10 km west of the mouth of Amawk Creek), the Sadlerochit Group also is represented by the Echooka Formation (Mull, 1982; Mull and others, 1987) which has a thickness of about 125 m. In these exposures, a lower succession of calcareous sandstone and siltstone passes upward through a sharp contact into black, phyllitic, silty shale. The lower succession contains brachiopods dated as Early Permian
(Mull and others, 1987). Here, the upper contact is sharp, and possibly represents a disconformity (Mull and others, 1987) between the Echooka and the overlying calcareous shale of the Shublik Formation. The Shublik consists of dark gray to black limestone, and carbonaceous and calcareous shale containing abundant phosphatic nodules. Pelecypods taken from several carbonate interbeds are interpreted to be late Middle to Late Triassic in age (cited in Mull and others, 1987, as written communication from N.J. Silberling). The Echooka represents a shallow marine transgressive succession (Detterman and others, 1975) that is overlain by basinal clastic and carbonate rocks of the Shublik. Also reported at Bombardment Creek is an exposure, about 2 m thick, of Triassic Karen Creek Sandstone (Mull, 1982; Mull and others, 1987).

**STRUCTURE**

Structures within the Blarney Creek and Apoon duplexes of the footwall assemblage (Doonerak multiduplex) are discussed separately below. In both duplexes, three generations of structures, comparable to those in the Endicott Mountains allochthon, are observed.

**Blarney Creek Duplex**

The Blarney Creek duplex is composed primarily of the Kayak Shale and carbonate rocks of the Lisburne Group. Minor slices of the Kekiktuk Conglomerate occur at the bottom of some horses, and one horse north of Amawk Creek contains a thin sliver of Permian Echooka Formation. The base of the duplex is occupied almost exclusively by the Kayak Shale, whereas the top of the duplex exposes mostly carbonate rocks of the Lisburne Group. Between the roof and floor thrusts, the section of Kayak and Lisburne is repeated in a number of imbricate horses. The horses generally merge smoothly with the roof and floor thrusts. In a few instances,
however, horses containing Lisburne limestone and Kayak Shale are decapitated by the roof thrust (Amawk thrust). The bottoms of some of the duplex horses carry laterally discontinuous slivers of Kekiktuk Conglomerate beneath the Kayak Shale, but in general the Kekiktuk is conspicuously absent from duplex horses.

Duplex horses exhibit a wide range in dimensions. They have thicknesses ranging from 100 to 500 m and can be traced from south-southeast to north-northwest (parallel to the tectonic transport direction) for up to 3 km. The horses are discontinuous along strike and have widths ranging from a few hundred meters to 5 km. Numerous lateral ramps are observed that dip shallowly to the east and west. The lateral ramp systems are best exposed in the north wall of Amawk Creek and on western Blarney Mountain. Along the northeastern flank of the Doonerak window, the duplex horses have shallow north and south dips. Proceeding clockwise around the eastern closure of the Doonerak window, however, the dips become consistently southerly.

The Blarney Creek duplex is preserved primarily along the northeastern flank of the Doonerak window, with only minor preservation on the southeastern flank (Fig. 1). On the north flank, the duplex is cut out to the west by the basal thrust (Amawk thrust) of the Endicott Mountains allochthon. Likewise, to the south, the characteristic carbonate rocks of the Blarney Creek duplex are absent and Devonian clastic rocks of the Beaucoup Formation (Endicott Mountains allochthon) rest directly on the fine-grained clastic rocks of the lower Paleozoic Apoon assemblage.

Within the Blarney Creek duplex, the limestone of the Lisburne Group rarely develops mesoscopic or microscopic structures. Occasional map scale structures are observed within the Lisburne, however. They are open to tight inclined folds with half-wavelengths of 400 to 800 m and amplitudes of 200 to 400 m. The development
of minor structures is largely confined to the Kayak Shale. The geometry and superpositional relations of the structures give important insight into the kinematic development of the duplex.

First-Generation Structures ($D_1$): The most prominent mesoscopic structural element within the Blarney Creek duplex is a penetrative cleavage ($S_1$). $S_1$ is the dominant structural fabric element of the Kayak Shale and in most instances it transposes bedding. Rare $D_1$ folds are found that consist either of poorly preserved rootless isoclines of thin sandstone interbeds or coherent isoclinal folds of crinoidal limestone interbeds. The $S_1$ cleavage consistently is axial planar to the minor folds. $S_1$ cleavage and bedding dip gently north on the northern flank of the Doonerak window (Fig. 6), but change to moderate to steep southeasterly dips around the eastern closure of the window. Sparse $D_1$ fold axis data illustrate a substantial variation in orientation. The variability is due, at least in part, to later deformation.

Second-Generation Structures ($D_2$): Second-generation structures ($D_2$) consist of gentle to open asymmetric folds and kink bands of bedding and $S_1$ cleavage. The folds have half-wavelengths ranging from millimeters to tens of meters. The $D_2$ folds and kinks have subhorizontal, northeasterly trending fold axes (Fig. 6). The $D_2$ axial planes and kink bands ($S_2$) usually dip moderately to steeply to the northwest, but southeast dips are sometimes observed. Rarely observed $D_2$ box folds display both orientations of axial planes. Usually, $D_2$ folds and kinks have an axial-planar crenulation cleavage that is found even in areas where $D_2$ folds or kinks are not observed. The orientation of $D_2$ structures does not vary between the north and south flanks of the Doonerak window.
Third-Generation Structures ($D_3$): Third-generation ($D_3$) structures are sporadically developed. They consist of a subvertical to steeply southwest dipping crenulation cleavage ($S_3$) that strikes northwest (Fig. 6). The $S_3$ cleavage overprints both $S_1$ and $S_2$ cleavages and is associated with rare $D_3$ folds. The folds have subvertical, northwest striking axial planes and northwest trending, subhorizontal fold axes. Like the $D_2$ structures, $D_3$ structures are consistently oriented throughout the Blarney Creek duplex.

Apon Duplex

Most of the rocks exposed in the Doonerak window lie within the Apon duplex. Along the northeastern margin of the window, the roof of the Apon duplex is the Blarney Creek thrust, whereas along most of the southern margin of the window, where the Blarney Creek duplex is absent, the roof is the Amawk thrust underlying the Endicott Mountains allochthon (Fig. 1).

In the eastern Doonerak window, four major horses, designated $H_1$, $H_2$, $H_3$, and $H_4$ from south to north in structurally descending order, compose the Apon duplex (Figs. 3 and 4). Each horse contains a different member of the Apon assemblage (Julian, 1989, 1993b). At a few isolated locations, all of which are immediately below the Blarney Creek thrust, the top of some of the Apon horses contains small exposures of Kekiktuk Conglomerate that show gradational depositional contacts with the underlying Apon rocks. In general, however, depositional contacts between the Kekiktuk and Apon are not preserved but rather have been tectonically modified.

The dimensions of the Apon duplex horses are poorly constrained, but within observable limits appear to differ substantially. The structurally highest horse ($H_1$) is about 3 km thick, but this figure is equivocal because the upper duplex
horse is cut by the out-of-sequence Eekayruk thrust (Phelps, 1987, 1993) that repeats the structural unit. Horse $H_2$ is 0.5 km thick, and horse $H_3$ is 1.5 km thick. The minimum thickness of the lowest horse ($H_4$) is 0.5 km, but it may be substantially thicker because the base of the horse is not exposed. The lowest duplex horse has an exposed width (i.e., measured perpendicular to the tectonic transport direction) of about 13 km; the overlying horses, all of which extend westward beyond the detailed map coverage, have widths of over 32 km. The length (measured parallel to the tectonic transport direction) of most of the horses is the least constrained dimension. The highest horse ($H_1$) is at least 4 km long and the underlying horse ($H_2$) is about 2 km long. Erosion complicates estimation of the subjacent horse ($H_3$), but its length is certainly 4 km or greater. The lowest horse ($H_4$) is exposed only locally and probably has a minimum length of on the order of a few kilometers.

For most of the Doonerak window, the horses and their bounding faults dip moderately to steeply to the southeast. As the Blarney Creek roof thrust is approached to the north, however, the three structurally lowest duplex horses roll over and become subhorizontal or dip shallowly to the north. The highest and lowest duplex horses ($H_1$ and $H_4$) are locally decapitated by the Blarney Creek thrust.

As in overlying structural units, three generations of superposed structures are recognized in the rocks of the Apoon duplex. Mesoscopic structures are best developed in fine-grained lithologies, but the structures are developed to some extent in all units.

First-Generation Structures ($D_1$): The oldest structures in the Apoon duplex form the most obvious fabric, which is a penetrative cleavage ($S_1$). The cleavage is
parallel to the axial planes of rarely preserved isoclinal folds of bedding and quartz veins. The cleavage is penetrative in fine-grained rocks but is poorly developed in massive volcanic units of the Apoon assemblage. Bedding is generally transposed into the $S_1$ orientation, except in the hinges of folds. $D_1$ folds of bedding range in amplitude from 20 cm to about 4 m; folds of quartz veins have amplitudes of 1 to 5 cm.

The $S_1$ cleavage generally strikes northeast and dips southeast within the Apoon duplex (Fig. 6). In the vicinity of the Blarney Creek thrust, dips are nearly horizontal, and near the northern margin of the Doonerak window, some $S_1$ surfaces dip gently to the north. This variation in $S_1$ surfaces results in a partial great-circle distribution of poles. The normal to the partial girdle distribution of $S_1$ poles corresponds to the mode of $D_2$ fold axes. $D_1$ fold axes generally plunge to the southeast and lie in the down-dip position of the axial plane.

**Second-Generation Structures ($D_2$):** Second-generation structures ($D_2$) are asymmetric folds and kink bands of bedding and the $S_1$ foliation. An axial-planar crenulation cleavage ($S_2$) is commonly developed in rocks that display a well-developed $S_1$ cleavage. $D_2$ folds have both rounded and chevron morphologies with maximum amplitudes of about 2 m, with less than 30 cm to millimeter scales being more prevalent. Axial planes of $D_2$ folds and $S_2$ crenulation cleavage generally dip steeply to the northwest, although occasionally they are found to dip southeast (Fig. 6). Rare box folds with conjugate axial planes have orientations consistent with the distribution of $S_2$ surfaces. $D_2$ fold axes are subhorizontal and northeast trending. The orientation of $D_2$ structures is consistent throughout all four horses of the Apoon duplex regardless of local $S_1$ orientations.
Third-Generation Structures ($D_3$): The youngest generation of structures ($D_3$) in the Apon duplex is represented by sporadically developed folds with subvertical, northwest striking axial planes and subhorizontal fold axes (Fig. 6). An $S_3$ crenulation cleavage parallels the axial planes of rare $D_3$ folds.

FOOTWALL BOUNDARY LAYER: BLARNEY CREEK THRUST

The Blarney Creek and Apon duplexes composing the Doonerak multiduplex are separated by a zone of decollement, the Blarney Creek thrust (Figs. 1 and 3). At the scale of mapping reported here, the Blarney Creek thrust generally appears as a single, well defined structure. In fact, in many areas the tectonic contact is sharp and only a few centimeters to meters wide. Nevertheless, over large areas the contact is actually a diffuse zone of decollement reaching a thickness of up to 250 m. Within the broad zones of deformation, slices of the Kekiktuk Conglomerate dominate, but occasionally thin sheets of Kayak Shale and rocks of the Apon assemblage are also found. Where the Kekiktuk is absent, the Blarney Creek thrust generally juxtaposes Kayak Shale directly on the underlying Apon assemblage, but in a few locations the Lisburne limestone rests directly on the Apon.

Thrust faults separating imbricate horses within the overlying Blarney Creek duplex sole into a decollement zone (floor thrust) within the Kayak Shale, generally without affecting the underlying Kekiktuk Conglomerate. Similarly, thrust faults within the Apon duplex merge upwards into a roof thrust that is located immediately below the Kekiktuk Conglomerate. The Kekiktuk itself behaves as a boundary layer within the Blarney Creek thrust zone that is essentially detached from both the Apon and Blarney Creek duplexes.
The geometry and structural history of the decollement zone separating the Blarney Creek and Apoon duplexes are quite complex and provide important constraints for developing kinematic models of footwall collapse during multiduplex formation. Along strike, the Blarney Creek thrust zone exhibits a number of complex structural and stratigraphic relations that are divided into two variants: (1) those where the Kekiktuk is in depositional contact with the underlying Apoon assemblage, and (2) those where the Kekiktuk is either absent or, where present, is structurally detached from the Apoon. These relations are described below for individual locations along the fault zone. See Fig. 7 for an index map showing the locations of each of the sites described below.

**Structurally Attached Kekiktuk Conglomerate**

Sites with preserved depositional relations between the Kekiktuk Conglomerate and the Apoon assemblage are pivotal for both structural and stratigraphic assessment of the Doonerak multiduplex. Several locations conclusively preserve depositional contacts. Commonly they are found at the upper contact of the Apoon duplex and preserve an original, although structurally modified, stratigraphic succession between the Apoon assemblage and rocks that are normally part of the Blarney Creek duplex or its boundary layer. On the other hand, in several locations the Blarney Creek thrust zone contains slivers of Apoon assemblage that overlie Kekiktuk Conglomerate which is resting depositionally above lower-plate Apoon assemblage rocks. These older-over-younger structural relations occur where the Blarney Creek thrust zone is a broad zone of distributed shear.
Figure 7. Index map showing the locations of Figs. 8 through 19. Symbols used repeatedly throughout these figures are: AT = Amawk thrust; BCT = Blarney Creek thrust; BL = detached boundary layer; ET = Eekayruk thrust; EMA = Endicott Mountains allochthon; BCD = Blarney Creek duplex; AD = Apoon duplex; Pe = Ehooka Formation (basal unit of Sadlerochit Group); MI = Lisburne Group; Mks = Kayak Shale; Mkc = Kekiktuk Conglomerate; H₁ = Apoon duplex Horse 1; H₂ = Apoon duplex Horse 2; H₃ = Apoon duplex Horse 3; H₄ = Apoon duplex Horse 4.
SOUTHERN FALSEOLA MOUNTAIN

Exposures on the southern flank of Falseola Mountain (Fig. 8) preserve a depositional contact between the Kekiktuk Conglomerate and phyllite of the underlying Apoon assemblage. The contact between the Apoon phyllite and the overlying Kekiktuk Conglomerate is sharp but gradational. Within a few meters below 1 to 2 m thick layers of conglomerate, phyllite typical of the Aapon assemblage is interbedded with fine-grained and coarse-grained lithologies belonging to the Kekiktuk Conglomerate. The transitional conglomerate and sandstone beds occur as channel-fill deposits with sharp lower contacts cut into phyllite. Beneath the channel-fill deposits is a transitional zone consisting of yellowish-green phyllite, typical of the base of the Kekiktuk, interbedded with black phyllite typical of the upper Aupon assemblage in horse $H_1$. The gradational nature of this depositional contact is difficult to reconcile with the contention of earlier workers that in the Doonerak window the Apoon assemblage and the overlying Kekiktuk Conglomerate are separated by an angular unconformity (Armstrong and others, 1976; Dutro and others, 1976; Mull, 1982; Mull and others, 1987). As pointed out by Julian (1993a), the lack of any pre-Brookian structures preserved in the Apoon assemblage and the apparently gradational nature of its contact with the Kekiktuk is decidedly different than relations observed in the northeastern Brooks Range (Oldow and others, 1987b). In the Doonerak window, the original, pre-Brookian contact between the Kekiktuk and the lower Paleozoic rocks of the Apoon clearly is not an angular unconformity, but it may represent a disconformity or possibly a low-angle unconformity.

Rocks of the Aapon assemblage and the Kekiktuk Conglomerate are intensely deformed. The dark gray phyllite of the Aapon assemblage contains a penetrative $S_1$ cleavage that is subparallel to bedding, which is recognized by sparse
Figure 8. Southern Falsoola Mountain. A locally continuous outcrop of Kekiktuk Conglomerate is in depositional contact with the underlying Apoon duplex; both units have the same orientation of \( S_1 \) cleavage. Discontinuous outcrops of Kekiktuk occur within the boundary layer separating the Apoon and Blarney Creek duplexes; the boundary-layer Kekiktuk has \( S_1 \) cleavage coincident with that in the overlying Blarney Creek duplex. Structural data are presented in lower-hemisphere, equal-area projections, where filled circles represent poles to \( S_0 \) or \( S_1 \) cleavage, and open circles represent \( D_1 \) fold axes. No vertical exaggeration on cross section; see caption of Fig. 7 for explanation of symbols.
1 to 3 cm intercalations of sandstone. The few preserved hinges of rootless isoclinal folds of sandstone within the Apoon assemblage have $S_1$ parallel to their axial planes. $S_1$ in the Apoon phyllite consistently dips between 20° and 50° to the southeast (Fig. 8). $S_1$ in the Kekiktuk Conglomerate also dips southeast and generally is at a large angle to bedding. In several locations the cleavage clearly passes continuously from the Apoon phyllite below into the overlying Kekiktuk. Occasionally, the orientation of $S_1$ is refracted in the more competent conglomerate, and this (together with $D_2$ folds) is responsible for much of the scatter in the $S_1$ data.

In many places, the Kekiktuk dips shallowly north, but in others the bedding is folded in mesoscopic tight to isoclinal $D_1$ structures. $D_1$ folds are upright or overturned to the north with the $S_1$ foliation parallel to their axial planes. The $D_1$ fold axes in the Kekiktuk are subhorizontal and trend northeasterly. They differ from the orientation of the $D_1$ fold axes in the underlying Apoon phyllite, which typically plunge to the southeast. The difference in fold axis orientation indicates that $D_1$ folds in the Apoon assemblage have been rotated, while those in the Kekiktuk Conglomerate have not been rotated. The orientations of the axial planes of $D_1$ folds in the Kekiktuk and the underlying Apoon are the same, however. Clearly, $D_1$ structures formed after deposition of the Carboniferous conglomerate.

Kayak Shale and Lisburne limestone structurally overlie most exposures of the lower-plate Kekiktuk along the southern flank of Falsoola Mountain. As previously indicated, the Kayak Shale is the preferred basal decollement of the Blarney Creek duplex. In two isolated instances, however, the Kekiktuk is incorporated in the upper plate of the Blarney Creek thrust near the base of the Blarney Creek duplex (Fig. 8), where it structurally overlies lower-plate Kekiktuk that is in depositional contact with the underlying Apoon. In these two locations, the upper-plate Kekiktuk is deformed and has a structural fabric with a geometry.
corresponding to that of the Blarney Creek duplex. $S_1$ is a penetrative cleavage that dips to the north at about 30° in the Kayak Shale and in phyllitic interbeds of the Kekiktuk, but $S_1$ is consistently refracted to steeper dips in the coarser parts of the Kekiktuk, where it appears as a spaced cleavage. $S_1$ in the upper-plate Kekiktuk lies at a high angle to the $S_1$ in the underlying Kekiktuk of the Apon duplex.

**NORTHERN HAMMOND RIVER**

West of the northern Hammond River (Fig. 9), quartzite of the Kekiktuk Conglomerate is exposed between overlying Kayak Shale and underlying Apon assemblage in horse $H_4$ of the Apon duplex. Bedding in the quartzite of the Kekiktuk dips 40° to 50° north-northwest, and the lower contact with the Apon is not exposed. $S_1$ cleavage in the Kekiktuk dips 20° to 45° southeast, comparable to $S_1$ in the Apon. The orientation of $S_1$ in the overlying Kayak Shale is north-northwest dipping at 20° to 45°. Thus, the Kekiktuk appears to be attached to the underlying Apon assemblage here, and the Blarney Creek thrust is located between the Kekiktuk and the Kayak Shale.

**KINNORUTIN MOUNTAIN**

On and near Kinnorutin Mountain, which is capped by a structural sheet composed of the Kekiktuk, Kayak and Lisburne, several laterally discontinuous outcrops of Kekiktuk Conglomerate are exposed within the Apon duplex (Fig. 10). West of the mountain, three isolated exposures are found. In one (Fig. 10, location D), the Kekiktuk lies along the structural contact between horses $H_3$ and $H_4$ of the Apon. In the other two exposures (just north of map location D), the Kekiktuk is found along thrusts within horse $H_3$. One intra-horse thrust can be traced to the east where it underlies the peak-capping structural sheet (discussed
Figure 9. Northern Hammond River. Coincidence of $S_1$ cleavage indicates that the Kekiktuk Conglomerate is structurally attached to the underlying Apoon duplex. There is a sharp structural break between the Apoon duplex, with south-dipping $S_1$ cleavage, and the overlying Kayak Shale, which has north-dipping $S_1$ cleavage and which belongs to the Blarney Creek duplex. Structural data are presented in lower-hemisphere, equal-area projections, where filled circles represent poles to $S_0$ or $S_1$ cleavage, and open circles represent $D_1$ fold axes. No vertical exaggeration on cross section; see caption of Fig. 7 for explanation of symbols.
Figure 10. Kinnorutin Mountain. East and west of the peak of Kinnorutin Mountain (shown by triangle/dot), discontinuous outcrops of Kekiktuk Conglomerate are in depositional and structural contact with the underlying Apoon duplex. The upper contacts of these discontinuous Kekiktuk outcrops are thrust faults that carry overlying imbricates of the Apoon duplex. Near the peak of Kinnorutin Mountain, the Kekiktuk Conglomerate occurs as a continuous boundary layer separating the Apoon and Blarney Creek duplexes. $S_1$ cleavage in both duplexes and within the boundary layer is essentially parallel and subhorizontal. Structural data for the Kekiktuk that is associated with the Apoon duplex east and west of the peak of Kinnorutin Mountain is presented in lower-hemisphere, equal-area projections, where filled circles represent poles to $S_0$ or $S_1$ cleavage, and open circles represent $D_1$ fold axes. Structural data for the boundary-layer Kekiktuk and adjacent units near the peak of Kinnorutin Mountain are presented in Fig. 17. No vertical exaggeration on cross section; see caption of Fig. 7 for explanation of symbols.
below) and re-emerges on the eastern flank of the mountain, where the Kekiktuk again is found along the intra-horse thrust.

West of Kinnorutin Mountain (Fig. 10, location D), the southernmost outcrop of conglomerate is about 20 m thick and ornaments the lower thrust plate between the horses $H_3$ and $H_4$. The Kekiktuk is involved in open to tight $D_1$ folds which have subhorizontal axes trending about N75°W. $S_1$ cleavage parallels the axial planes and dips 10° to 30° to the south-southwest. Cleavage in the volcanic rocks of the underlying Apoon dips southwest at 20° to 40°, more or less coincident with that in the Kekiktuk. The Kekiktuk appears to overlie rocks of horse $H_4$ depositionally, but is preserved only locally.

The northern two outcrops are entirely surrounded by rocks of the horse $H_3$. The more southerly of the two is very small and poorly exposed and as a result no structural observations were possible. The northern exposure of Kekiktuk has a maximum thickness of about 6 m and has sharp contacts with the enclosing Apoon rocks. No folds were observed in the Kekiktuk and bedding dips between 25° and 60° to the north-northeast. $S_1$ cleavage generally has dips of less than 30° to the south-southwest. In the Apoon rocks both above and below the Kekiktuk, $S_1$ has variable strikes and dips of less than 40°; part of the scatter is due to $D_2$ folds. The Kekiktuk rests depositionally on the underlying Apoon and serves as a distinctive marker in tracing the intra-horse thrust. Where the Kekiktuk is absent to the east, the fault is located with difficulty.

Northeast of and just beneath the mountain-capping stack of Kekiktuk, Kayak, and Lisburne, a north-dipping, 10 m thick layer of Kekiktuk Conglomerate is sandwiched between minor thrust slices of horse $H_3$ of the Apoon duplex (Fig. 10, location K). The Kekiktuk layer is internally folded, its enveloping surface dips 50° to the north, and it contains an $S_1$ cleavage which generally is subhorizontal but
which locally dips steeply to the south. Cleavage and bedding in the Apoon, both above and below the Kekiktuk, are subhorizontal. Nevertheless, the Kekiktuk here probably rests depositionally on the underlying Apoon, in a manner similar to relations observed on the western flank of the mountain.

**NORTHERN AMAWK MOUNTAIN**

Kekiktuk Conglomerate is exposed at several locations along the steep north face of Amawk Mountain. Most of the exposures are cut on their northern side by east-west or northeast striking high-angle faults, which appear to control the topography of this face of the mountain. Most of the exposures form north-dipping flatirons lying to the south of the high-angle faults (Fig. 11).

The flatirons exhibit minor differences in the number of stratigraphic units exposed. Each has the Kekiktuk Conglomerate at its base. The easternmost flatiron has Kayak Shale overlying the Kekiktuk, as does the central flatiron, which is unique in being capped by Lisburne limestone. The westernmost flatiron exposes only the Kekiktuk Conglomerate.

The three flatirons have similar structural fabrics (Fig. 11). Bedding in the Kekiktuk Conglomerate mostly shows north dips of 30° to 90°, with the variability a product of mesoscopic $D_1$ folds. Where preserved, bedding in the Kayak and Lisburne also dip northerly.

In these outcrops, $S_1$ cleavage in fine-grained clastic rocks of the Apoon assemblage ($H_3$) dips shallowly (less than 30°) in virtually all directions. Bedding in the overlying Kekiktuk Conglomerate generally dips shallowly to steeply north and is cross-cut by $S_1$ cleavage with dips ranging from nearly horizontal to about 45°. Bedding-cleavage intersections in the Kekiktuk are consistently at a high angle. Although closure is not observed, the bedding-cleavage relations indicate that the
Figure 11. Northern Amawk Mountain. Several outcrops of Kekiktuk Conglomerate, exposed in north-dipping flatirons, are structurally attached to the underlying Apoon duplex, and structurally detached from the overlying Blarney Creek duplex. S1 cleavage in the Apoon duplex is somewhat variable in orientation, but is clearly discordant with the consistently north-dipping S1 cleavage observed in the Blarney Creek duplex. Structural data are presented in lower-hemisphere, equal-area projections. For the Kekiktuk at location W, poles to S0 are represented by open circles and poles to S1 cleavage are represented by filled circles; for the Apoon at location W, poles to S1 cleavage are represented by filled circles. For the area of cross section X-X', data for the Kayak Shale and the Lisburne Group are combined, with poles to S0 and S1 cleavage represented by filled circles for the Kayak, and with poles to S0 and S1 cleavage represented by open triangles for the Lisburne. For the Kekiktuk and Apoon assemblage near X-X', filled circles represent poles to S0 or S1 cleavage, and open circles represent D1 fold axes. For all units in the area of cross-section Y-Y', poles to S0 and S1 cleavage are represented by filled circles, and D1 fold axes are represented by open circles. No vertical exaggeration on cross section; see caption of Fig. 7 for explanation of symbols.
flat-irons represent the hinge of a $D_1$ fold. Here as elsewhere, $D_1$ structures in the Apoon assemblage are at least post-Carboniferous in age. $S_1$ cleavage in the Kayak dips north at 10° to 45°, indicating that the Blarney Creek thrust separates the Kayak from the underlying Kekiktuk.

**AMAWK CREEK**

In Amawk Creek, the Blarney Creek thrust is down-dropped to the north and concealed by a high-angle fault that places rocks of the Apoon assemblage in direct contact with the Lisburne limestone (Fig. 12). On the south wall of the canyon, south of the high-angle fault, however, the Blarney Creek thrust is exposed. The thrust lies within the Kayak Shale and isolates a small exposure of Kekiktuk Conglomerate and a thin layer of Kayak Shale in its footwall. In this restricted area, the Kekiktuk Conglomerate is in depositional contact with Apoon volcanic rocks of horse $H_4$. The Kekiktuk and the thin interval of Kayak Shale are folded together with the underlying Apoon assemblage rocks in a $D_1$ syncline. The syncline has an axial plane dipping about 20° to the south-southeast and a west-southwest trending fold axis with a plunge of about 15°. $S_1$ foliation within the Kekiktuk and Kayak parallel the axial plane of the fold. $S_1$ in the Kayak is reoriented by $D_2$ folds, which do not affect the Kekiktuk or the rocks of $H_3$. The cleavage is well developed in the volcanic rocks of the Apoon and is consistent in orientation with that developed in the finer-grained parts of the Kekiktuk.

The syncline is truncated by the overlying Blarney Creek thrust, which can be traced with confidence from the top to the bottom of the canyon wall (about 300 m of vertical relief). In the upper plate, bedding and cleavage in the Kayak Shale are highly variable, but generally dip to the northeast. Across the structural contact
Figure 12. Amawk Creek and Wien Creek. South of Amawk Creek, Kekiktuk Conglomerate is in depositional contact with the underlying Apoon assemblage. The Apoon, Kekiktuk and overlying Kayak Shale are all folded in a D$_1$ syncline, which is truncated by the overlying Blarney Creek thrust. At Wien Creek, however, discordant S$_1$ cleavage relations clearly show that the Kekiktuk is structurally detached from the underlying Apoon duplex; here the Kekiktuk is part of the boundary layer separating the Apoon duplex from the Blarney Creek duplex. Structural data are presented in lower-hemisphere, equal-area projections, where filled circles represent poles to S$_0$ or S$_1$ cleavage, and open circles represent D$_1$ fold axes. No vertical exaggeration on cross section; see caption of Fig. 7 for explanation of symbols.
between Kayak Shale in the upper and lower plates, bedding and $S_1$ are clearly discordant.

**Wien Mountain**

On Wien Mountain (Fig. 13), Kekiktuk Conglomerate rests on volcanic and volcanogenic rocks of horse $H_4$ of the Apoon duplex and is exposed south of an east-northeast striking high-angle fault. The fault down-drops the Blarney Creek duplex to the north against the Apoon duplex lying to the south. The Kekiktuk dips shallowly to moderately to the north-northwest ($10^\circ$ to $50^\circ$) and has a poorly developed $S_1$ cleavage with nearly horizontal dips. The underlying Apoon assemblage has shallowly west dipping bedding (up to $30^\circ$) and shallow, southeast dipping $S_1$ cleavage (up to $35^\circ$) that apparently is consistent in orientation with that in the overlying Kekiktuk.

The Kayak Shale in this location has bedding and $S_1$ cleavage that are essentially parallel and which dip northwest at about $30^\circ$. The orientations of $S_1$ cleavage in the Kayak Shale and in the underlying Apoon assemblage are clearly discordant and although the cleavage is poorly developed in the Kekiktuk, it appears to be allied with that in the Apoon. Thus the Blarney Creek thrust is interpreted as lying between the Kekiktuk and the Kayak Shale. Resting above the Kayak Shale is a small klippe of Apoon assemblage. $S_1$ cleavage within this klippe of Apoon assemblage rocks is parallel to that of the structurally underlying Kayak. The klippe apparently is the erosional remnant of a rare slice of Apoon that was incorporated into the base of the Blarney Creek duplex.

**Structurally Detached or Structurally Removed Kekiktuk Conglomerate**

The Kekiktuk Conglomerate has been stripped from the underlying Apoon assemblage at several locations along the Blarney Creek thrust. At these locations,
Figure 13. Wien Mountain. The Kekiktuk Conglomerate is structurally attached to the underlying Apoon duplex, which has south-dipping $S_1$ cleavage. Overlying the Kekiktuk is Kayak Shale in the Blarney Creek duplex, which has north-dipping $S_1$ cleavage. Above the Kayak Shale is a small klippe of Apoon assemblage; north-dipping $S_1$ cleavage in the klippe indicates that it is part of the Blarney Creek duplex. Structural data are presented in lower-hemisphere, equal-area projections, where filled circles represent poles to $S_0$ or $S_1$ cleavage. No vertical exaggeration on cross section; see caption of Fig. 7 for explanation of symbols.
where the upper and lower duplexes are in direct contact (i.e., with no intervening boundary layer), the thrust is a sharp structural discontinuity. In several locations, the Kekiktuk demonstrably is stripped from the underlying Apon but still is found at the contact between the upper and lower duplexes. At two of these locales, the detached Kekiktuk is readily differentiated from places where it is in depositional contact with the Apon by: (1) the presence of a shear zone between the Kekiktuk and underlying Apon, and (2) a pronounced discordance in the orientation of $S_1$ cleavage across the contact. In other locations, structural relations are complex and numerous imbricates of Apon assemblage and Carboniferous rocks lie within a shear zone. In some areas, evidence for structural detachment of the Kekiktuk from the substratum is not compelling but the interpretation that a detachment exists is allowable.

**WESTERN FALSOOLA MOUNTAIN**

Where the Kekiktuk is preserved both above and below the basal Blarney Creek thrust, as described above on south Falsoola Mountain, the differences in the orientation of $S_1$ cleavage conclusively document detachment of the upper-plate conglomerate from the underlying Apon. Elsewhere on Falsoola Mountain, particularly on the western flank immediately east of Blarney Creek (Fig. 14), relationships are not as clear. In this area, the Kekiktuk Conglomerate occurs discontinuously at the boundary between the two footwall duplexes. The structural fabric, particularly the orientation of $S_1$ cleavage, within the isolated exposures of the Kekiktuk is consistent with that of both the upper and lower duplexes. $S_1$ cleavage and bedding are parallel within the Kekiktuk and, like cleavage in the overlying Kayak Shale and underlying Apon, dip shallowly ($10^\circ$ to $30^\circ$) to the southeast. Conceivably, the Kekiktuk along the contact is in depositional contact
Figure 14. Western Falsoola Mountain. Kekiktuk Conglomerate occurs discontinuously along the detached boundary layer between the Apoon and Blarney Creek duplexes. $S_1$ cleavage is consistently oriented in both duplexes and in the boundary layer that separates them. Structural data are presented in lower-hemisphere, equal-area projections, where filled circles represent poles to $S_0$ or $S_1$ cleavage. No vertical exaggeration on cross section; see caption of Fig. 7 for explanation of symbols.
with the underlying Apoon assemblage and is part of a preserved limb of a D₁ isoclinal fold. However, considering the discontinuous nature of the conglomerate and its similarity to allochthonous Kekiktuk elsewhere along the contact exposed on southern Falsoola Mountain, the lower contact is interpreted to be tectonic.

**Wien Creek**

At Wien Creek (Fig. 12), discordant S₁ cleavage relations clearly document the detachment of the Kekiktuk Conglomerate from the underlying Apoon assemblage. The conglomerate is exposed along the east wall of the valley and lies above the lowest horse of the Apoon duplex. Above the Kekiktuk, two horses of the Blarney Creek duplex repeat the Kayak Shale and Lisburne limestone section. Bedding and S₁ cleavage in the Apoon horse dips 20° to 30° to the south. Bedding in the Kekiktuk is not folded in minor structures, and it dips consistently to the north at 30° to 50°. S₁ cleavage in the Kekiktuk is parallel to bedding and also dips to the north, concordant with that of the overlying Kayak and Lisburne.

**Lost Sheep Creek**

For part of its course, Lost Sheep Creek flows along the trace of an east-west trending high-angle fault that cuts earlier contractional structures. A complex imbricate stack of Apoon and Carboniferous lithologies is preserved in the canyon (Fig. 15).

Exposures south of the high-angle fault are poor due to extensive cover by vegetation. An exposure of Apoon volcanic rocks in and near the creek bottom contains poorly developed S₁ cleavage that dips southeast at 20° to 40° (Fig. 16). The volcanic rocks are structurally overlain by a thin unit of Kayak Shale containing crinoidal packstone. The Kayak Shale is, in turn, structurally overlain by a thin sheet of Kekiktuk Conglomerate, which on the basis of graded beds is known to be
Figure 15. Lost Sheep Creek. South of the high-angle fault, two horses of the Apoon duplex are separated by thin imbricates of Kayak Shale and Kekiktuk Conglomerate. North of the high-angle fault, the Apoon duplex contains south-dipping $S_1$ cleavage, and is overlain by structurally attached Kekiktuk Conglomerate. Overlying the attached Kekiktuk is a slice of Apoon assemblage that contains north-dipping $S_1$ cleavage, as do several small overlying imbricates of the Kekiktuk, Kayak and Lisburne. Structural data for Lost Sheep Creek are illustrated in Fig. 16. No vertical exaggeration on cross section; see caption of Fig. 7 for explanation of symbols.
Figure 16. Structural data for Lost Sheep Creek (see Fig. 15 for locations) are presented in lower-hemisphere, equal-area projections, where filled circles represent poles to $S_0$ or $S_1$ cleavage, and open circles represent $D_1$ fold axes.
stratigraphically upright. The Kayak is poorly exposed and yielded only one measurement of $S_1$ cleavage, which dips 45° to the east. Bedding and $S_1$ cleavage in the overlying Kekiktuk dip 20° to 40° to the east and southeast and are coincident with $S_1$ orientations in the underlying Apon volcanic unit. The upright sliver of Kekiktuk is structurally overlain by poorly exposed volcanioclastic rocks of horse $H_3$ of the Apon duplex that contain $S_1$ cleavage dipping shallowly to the southwest.

The rocks of horse $H_3$ are well exposed on the north side of the high-angle fault, where they contain a penetrative $S_1$ cleavage dipping south between 40° and 60°. Above the Apon is an unusually thick section (about 150 m) of Kekiktuk Conglomerate. The unusual thickness of the Kekiktuk here is probably due to imbricate stacking and/or $D_2$ folding. The Kekiktuk is deformed in tight to isoclinal $D_1$ folds and with a penetrative $S_1$ cleavage parallel to the axial planes. The $S_1$ cleavage orientation is variable due to superposed $D_2$ foliès, but for the most part is consistent with the $S_1$ cleavage in the underlying Apon. A 60 m section of Apon volcanic rocks overlying the Kekiktuk is penetratively deformed by a north 10° to 30° dipping $S_1$ cleavage. The volcanic rocks of the Apon are themselves structurally overlain by thin multiple imbricates of the Kekiktuk, Kayak, and Lisburne which also exhibit shallow, north-dipping $S_1$ cleavage. The lack of preserved stratigraphic contacts in the imbricate stack of Carboniferous rocks is indicated by laterally discontinuous slivers of Kekiktuk, Kayak, and Lisburne. In the westernmost sliver, a double repetition of Kekiktuk, Kayak, and Lisburne is observed.

In this area, definition of the boundary between the Apon and Blarney Creek duplexes becomes blurred. Using the orientation of $D_1$ structures as a guide, however, allows a plausible segregation. The basal part of the structural stack has $S_1$ cleavage dipping southerly, consistent with that of the underlying Apon duplex farther south. On the other hand, the upper part of the imbricate stack exhibits $D_1$
structures with northerly dips, consistent with those of the overlying Blarney Creek duplex. Thus, based on associations of D₁ structures, the imbricate zone can be divided and assigned to the upper and lower duplexes.

Such a simple division of the imbricate stack obscures a critical structural relation, however. Of major importance is the recognition that the imbricate stack is localized at the structural boundary between the two duplexes. Particular constituents of the imbricate zone are not found in the superjacent and subjacent duplexes: Apoon assemblage rocks are rarely found within the Blarney Creek duplex, and then only at the base, and similarly, Carboniferous clastic and carbonate rocks seldom are found in the Aapon duplex except near its upper contact.

The implication is that even though parts of the imbricate zone have structural affinities either with the upper or lower duplex, together they form a separate structural entity, the Blarney Creek thrust zone. Here, rocks of the underlying and overlying assemblages are complexly imbricated within the broad shear zone, but were not carried away from the shear zone into either adjacent structural unit.

**KINNORUTIN MOUNTAIN**

On the peak of Kinnorutin Mountain (Fig. 10), the Kekiktuk forms a continuous horizon separating the Apoon and Blarney Creek duplexes. The upper duplex is dominated by an exposure of relatively flat-lying Lisburne limestone that constitutes the top of the peak. The limestone is underlain by the Kayak Shale and Kekiktuk Conglomerate. On the north side of the peak, the Kayak is omitted for a short interval where the Lisburne limestone rests directly on the Kekiktuk Conglomerate. The Carboniferous rocks sit above a small-scale imbricate within horse H₃ of the Apoon duplex. The orientation of S₁ cleavage in all units, including
the Apoon, shows substantial variability but essentially is subhorizontal (dips occur in almost all directions, usually at 30° or less; Fig. 17). The contact between the Apoon and the Kekiktuk is locally well exposed and is sharp, without the gradational relations observed farther east.

The lack of structural discordance in $S_1$ between the top of the Apoon duplex, the overlying Kekiktuk, and the Blarney Creek duplex obscures the relation of the Kekiktuk to the Blarney Creek thrust zone. Using only $S_1$ orientations, it cannot be demonstrated that the conglomerate is detached from the underlying Apoon assemblage. This structural relationship is encountered in several other locations along the contact and results in ambiguity in tracing the bottom of the Blarney Creek thrust zone. At Kinnorutin Mountain, however, the Kekiktuk Conglomerate clearly sits structurally above the Apoon duplex. This is shown by the continuity of an imbricate fault within horse $H_3$ of the Apoon duplex beneath the Kekiktuk (Fig. 10). The previously described intra-horse fault relations cannot be attributed to a pre-Carboniferous event, because the Kekiktuk Conglomerate resides in the lower plate of the imbricated Apoon succession.

**WESTERN BLARNEY MOUNTAIN**

For most of its exposed length along western Blarney Mountain (Fig. 18), the Blarney Creek thrust places Kayak Shale in direct contact with the Apoon assemblage, with no intervening boundary layer. Locally, however, a thin slice of Kekiktuk Conglomerate lies between the Apoon and Blarney Creek duplexes. Here, as seen locally on western Falsoola Mountain, the $D_1$ structural fabric in the Kekiktuk and the overlying and underlying duplexes is the same.

Clearly in this instance, it is not possible to document the existence of detachment of the Kekiktuk from the underlying Apoon. Only in areas of
Figure 17. Structural data for the boundary-layer Kekiktuk and adjacent units near the peak of Kinnorutin Mountain (see Fig. 10 for location) are presented in lower-hemisphere, equal-area projections, where filled circles represent poles to $S_0$ or $S_1$ cleavage, and open circles represent $D_1$ fold axes.
Figure 18. Western Blarney Mountain. Kekiktuk Conglomerate is sporadically present in the boundary layer between the Apoon and Blarney Creek duplexes. Whether the Kekiktuk is present or absent, the $D_1$ structural fabric in the two duplexes as well as in the detached boundary layer has the same orientation. Structural data are presented in lower-hemisphere, equal-area projections, where filled circles represent poles to $S_0$ or $S_1$ cleavage, and open circles represent $D_1$ fold axes. No vertical exaggeration on cross section; see caption of Fig. 7 for explanation of symbols.
pronounced discontinuity of $D_1$ fabrics or where other structural relations are compelling, such as those described at Kinnorutin Mountain, can detachment be proved. Where the Kekiktuk is discontinuous along the contact, however, it is reasonable to attribute its absence to tectonic removal. Although equivocal, the correspondence between the structural fabric in the Kekiktuk and in the Blarney Creek duplex is interpreted to allow for its detachment from the underlying Apon.

**NORTHERN BLARNEY CREEK**

In two areas along northern Blarney Creek (Fig. 19), Lisburne limestone is in direct contact with underlying rocks of the Apon duplex. The complete omission of Kayak Shale and the Kekiktuk Conglomerate from the contact between the two duplexes demands a tectonic origin for the contact. The western exposure of this fault contact is poorly exposed and no mesoscopic structural data are available. Mapping in this area, however, indicates that the Lisburne actually overlies two sheets of Apon assemblage rocks. Where the Kayak Shale is cut out on the north, the Lisburne overlies rocks of Apon horse $H_3$. Tracing the contact to the south, the Lisburne and horse $H_3$ are separated by a thin wedge of Apon volcanic rocks. Map relations suggest that the northward thinning wedge of Apon volcanic rocks is one of the tectonic slices found within the diffuse Blarney Creek thrust zone exposed in Lost Sheep Creek 0.5 km to the south.

Exposure of the Lisburne-Apon contact east of Blarney Creek is much clearer. There the orientation of $S_1$ cleavage found both in the Lisburne and the Apon approximately parallels the contact and dips east at $10^\circ$ to $50^\circ$. It is notable that this is one of the few locations where $S_1$ cleavage is penetratively developed in Lisburne carbonate rocks, which may indicate that its development is related to shear on the Blarney Creek thrust. Normally, intense shear was localized in the
Figure 19. Northern Blarney Creek. Locally in this area, Lisburne limestone is in direct structural contact with underlying rocks of the Apoon duplex, with the normally intervening Kayak Shale and Kekiktuk Conglomerate having been tectonically removed. Structural data are presented in lower-hemisphere, equal-area projections, where filled circles represent poles to $S_0$ or $S_1$ cleavage. No vertical exaggeration on cross section; see caption of Fig. 7 for explanation of symbols.
mechanically incompetent Kayak Shale, effectively insulating the Lisburne from the effects of shearing in most instances.

**KINEMATIC RECONSTRUCTION**

The internal structural relations of the Blarney Creek and Apoon duplexes, when viewed individually, are consistent with simple models of duplex formation. The Blarney Creek duplex, in particular, has a classic duplex morphology. The floor and roof of the Blarney Creek duplex are respectively "tiled" and "shingled" almost entirely with rocks of a single stratigraphic unit: the floor of the duplex is composed mostly of Kayak Shale, and the roof is composed almost entirely of Lisburne Group carbonates. The Kekiktkuk Conglomerate is sporadically present within the Blarney Creek duplex, at the base of some of the horses. In addition, rocks of the Sadlerochit Group and Shublik Formation are occasionally included at the top of a horse. These observations imply that during construction of the Blarney Creek duplex, the floor thrust was located primarily within the Kayak Shale and that, in general, the Kayak Shale was detached from the underlying Kekiktkuk Conglomerate during this kinematic episode. Occasionally, however, small slices of Kekiktkuk remained attached to the Kayak and were thereby carried up above the floor of the Blarney Creek duplex at the bottom of a horse. Similarly, the roof thrust was generally located either within or, more probably, at the top of the Lisburne Group carbonates during duplex formation. Since the Lisburne Group is a thick and structurally competent unit, it is no surprise that nucleation of the Amawk thrust, later to become the roof thrust of the Blarney Creek duplex, occurred at the top of the carbonates near their contact with overlying, less competent clastic rocks of the Sadlerochit Group. Only rarely were small sheets of the post-Lisburne strata left
behind (i.e., below the Amawk thrust), to be incorporated later within horses of the Blarney Creek duplex.

As discussed by Julian (1989, 1993a), the internal structure of the Apoon duplex requires a more complex imbrication history for its development than for that of the Blarney Creek duplex. Simple northward propagation of the floor thrust cannot account for the internal geometry of the Apoon duplex. Rather, horse imbrication involved out-of-sequence fault overstepping. Although complicated, the imbrication history of the Apoon duplex is a minor variant of existing models (e.g., Butler, 1982a).

It is only when the entire footwall assemblage of the Dooneraak multiduplex is viewed as a coherent unit that the complex behavior of interaction between its component structures becomes apparent. Attempts to unravel the kinematic history of the stacked footwall duplexes focus attention on the role of the boundary that separates them, the Blarney Creek thrust zone.

**Boundary Layer Kinematics: Blarney Creek Thrust Zone**

Assessment of structural and stratigraphic relations exposed along the Blarney Creek thrust zone and within the Apoon and Blarney Creek duplexes indicates that the Kekiktuk Conglomerate deformed more or less independently of the bounding duplexes. The simple fact that the Kekiktuk Conglomerate is rarely found among the horses of the overlying and underlying duplexes indicates its predominant lack of direct involvement in their formation. For the overlying Blarney Creek duplex, this can be explained easily by the preferential development of the floor thrust in the mechanically weak Kayak Shale overlying the Kekiktuk. The great paucity of Kekiktuk Conglomerate exposures between the four horses of the Apoon duplex, on the other hand, cannot be explained as simply.
Evidence that the Kekiktuk Conglomerate originally was in depositional contact with the Apoon assemblage is found in three of the four Apoon duplex horses. Widespread exposures of Kekiktuk in depositional contact with fine-grained clastic rocks of the Apoon horse $H_4$ are found along the south flank of Falsoola Mountain (Fig. 8). Small exposures of Kekiktuk in depositional contact with the interbedded fine-grained clastic and volcanogenic rocks of horse $H_3$ are preserved east and west of Kinnorutin Mountain (Fig. 10) and as flatirons on the north face of Amawk Mountain (Fig. 11). Similarly, small outcrops of the Kekiktuk depositionally overlie volcanic rocks of horse $H_4$ just west of Kinnorutin Mountain (Fig. 10), in Amawk Creek (Fig. 12), and near the top of Wien Mountain (Fig. 13).

During imbrication of the Apoon duplex, the Kekiktuk Conglomerate must have been tectonically stripped from the underlying Apoon assemblage rocks in most cases. Thus, the Kekiktuk constitutes an independent tectonic unit bound both above and below by thrust faults. The Blarney Creek thrust, then, is not a discrete structural surface everywhere along its trace. Rather, the fault is a decollement zone, composed of an anastomosing system of faults localized near the stratigraphic horizon of the Kekiktuk Conglomerate. If this were not the case, one would expect to find the Kekiktuk at the base of horses within the Blarney Creek duplex and/or at the tops of horses in the Apoon duplex.

The character of the Blarney Creek fault zone varies considerably along its trace. As shown in Lost Sheep Creek of eastern Blarney Mountain (Fig. 15), the fault zone does not exclusively contain rocks of the Kekiktuk, but also includes small slices of the underlying Apoon and overlying Kayak and Lisburne. Similar relations are observed on western Falsoola Mountain (Fig. 14) and on Wien Mountain (Fig. 13), as described above, and also near Trembley Creek at the eastern closure of the Doonerak window (Phelps, 1987, 1993). In other segments of the fault zone,
such as northern Hammond River (Fig. 9), northern Blarney Creek (Fig. 19), and western Blarney Mountain (Fig. 18), the tectonic boundary is sharp and well defined. Where it is well defined, the Blarney Creek thrust generally omits structural section and variably places rocks of the Kekiktuk, Kayak, or Lisburne on rocks of the underlying Apon assemblage.

Mesoscopic structures both within and below the Blarney Creek thrust zone indicate that initiation of and continued motion along the fault occurred during $D_1$ deformation. In virtually all instances where the Kekiktuk Conglomerate lies below the Blarney Creek thrust zone and clearly is in depositional contact with the underlying Apon assemblage, $S_1$ cleavage intersects bedding at a large angle. This is because the depositional contacts are preserved in the hinges of decapitated $D_1$ synclines involving both the Kekiktuk and the underlying Apon. Where the Kekiktuk is exposed within the fault zone, $S_1$ cleavage and bedding generally are subparallel (except in the hinges of minor folds), representing detached limbs of large-scale tight to isoclinal $D_1$ folds.

Figure 20 illustrates forward models of boundary layer deformation, which account for decapitation of $D_1$ synclines in the footwall, omission of units, and inclusion of minor slices of Apon, Kayak, and Lisburne in the Blarney Creek thrust zone. North-vergent $D_1$ folds of the interface between the Kekiktuk Conglomerate and the underlying Apon assemblage were formed in a north-directed (top-to-the-north) shear couple. The upper fault strand of the boundary layer shear zone was localized in the Kayak Shale and it accommodated imbrication of the superjacent Blarney Creek duplex. The lower fault strand of the shear zone accommodated imbrication of the subjacent Apon duplex, and was nucleated within the Apon assemblage below the upright lower limbs of major asymmetric tight to isoclinal folds of the Kekiktuk-Apon interface. Displacement on anastomosing faults within
Figure 20. Forward kinematic models illustrating the development of complex detached boundary layer relationships. See Fig. 7 for explanation of symbols.

A. Mixing of Blarney Creek duplex and Apoon duplex lithologies within the boundary layer.

B. Horse decapitation leading to angular juxtaposition of S1 cleavage across the boundary layer.

C. Horse decapitation leading to omission of stratigraphic section, and the development of a structural contact between the Lisburne and the Apoon assemblage at the boundary layer.
the shear zone can result in decapitation of $D_1$ synclines and inclusion of small slices of Apon rocks above the fault zone. The profound imbrication of units preserved in Lost Sheep Creek (Fig. 15) can be explained, at least in part, by such a system of anastomosing faults formed between the upper and lower boundaries of the shear zone.

Duplex horse decapitation, evidenced by the omission of structural section and the juxtaposition of units with highly discordant $S_1$ foliations, requires an additional component in this model. If imbricate faults within the underlying Apon duplex merged sequentially, in a forward-propagating manner, with the lower strand of the Blarney Creek thrust zone, as predicted by simple duplex models, no major omission of section nor substantial discordance between $S_1$ cleavage orientations above and below the fault would be expected. Thus, it appears that imbricate horses of the lower duplex did not always merge smoothly with their roof thrust, but rather created local asperities in the fault zone (in a sequential model, such asperities would result in forward propagation of the ramp). Predictably, such irregularities in the boundary layer fault zone would be truncated by new strands formed to maintain a smooth fault trajectory. Depending upon the magnitude of the asperity, varying amounts of section can be removed in this manner, resulting in such dramatic juxtapositions as the Lisburne on the Apon observed in northern Blarney Creek (Fig. 19).

Formation of the Blarney Creek thrust zone followed development of tight to isoclinal $D_1$ folds involving the Kekiktuk Conglomerate and adjacent units. Discordance of $D_1$ structures and omission of section across the fault zone indicate that decapitation of horses resulted from continued displacement on the fault zone during Apon duplex imbrication. Thus, the fault zone continued activity throughout $D_1$ and formation of the underlying Apon duplex. Similarly, local
truncation of horses at the top of the Blarney Creek duplex indicates continued motion on the Amawk thrust during subjacent duplex imbrication.

**Relative Timing of Footwall Collapse Structures**

An important consideration that arises from recognition of the stacked duplexes in the Doonerak window and their relation to the Blarney Creek thrust zone is an assessment of the relative timing of their structural development. It is of particular importance to address the alternative interpretations of serial versus simultaneous development of the duplexes and their intervening boundary layer during footwall collapse. Many of the first-generation kinematic models for the evolution of duplexes employed a serial sequence of forward-propagating displacements (e.g., Boyer and Elliot, 1982). More recent models, however, either allow or require simultaneity of displacements within or among duplexes (Boyer, 1986b; Fermor and Price, 1987; Yin and others, 1989). Consequently, there is a growing awareness that contemporaneous motions on separate faults may be a common feature in the formation of duplexes, and probably also in the general scheme of fold and thrust belt evolution.

The geometric relations among the three phases of mesoscopic structures observed within the Blarney Creek duplex, the Blarney Creek thrust zone, and the Apoon duplex provide important relative timing constraints for the imbrication history. In each of these three structural units, as explained below, imbrication occurred during $D_1$ deformation and before the development of superposed $D_2$ and $D_3$ structures.

Along the northern margin of the Doonerak window, where most of the Blarney Creek duplex is exposed, the horses and constituent lithologic units dip gently to the north. Only on the southeastern flank of the Doonerak window,
around the closure of the east-northeast trending antiform, do faults and bedding within the Blarney Creek duplex dip south. Strains associated with \( D_1 \) structures are large as indicated by nearly complete transposition of bedding into the orientation of \( S_1 \) cleavage, and planar \( D_1 \) structures are consistently oriented approximately parallel to the faults within the duplex. On the north flank of the Doonerak window, \( D_1 \) fabrics and bedding within the Blarney Creek duplex dip shallowly north, whereas on the southeast flank, the same fabric elements dip to the south. \( D_2 \) and \( D_3 \) structures within the Blarney Creek duplex have the same orientations on both flanks of the Doonerak window. The axial surfaces of \( D_2 \) folds and associated axial-planar cleavage consistently strike northeasterly and have steep northwesterly dips; subordinate southeast dips are interpreted as belonging to conjugate \( D_2 \) folds. \( D_3 \) structures throughout the region have steeply dipping, north-northwest striking axial surfaces and associated cleavage. \( D_3 \) structures clearly postdate development of the Doonerak multiduplex. \( D_2 \) structures, on the other hand, either postdate duplex formation or, considering their correspondence in orientation to the multiduplex, may represent a final stage of duplex deformation (Avé Lallemant and Oldow, 1993).

Similar structural relations are found in rocks composing the Blarney Creek thrust zone. Within the thrust zone, exposures of the Kekiktuk Conglomerate and less common slices of the Apoon assemblage, Kayak Shale, and Lisburne Group, have the same generations of structures. Some of the coarse clastic, volcanic, and carbonate rocks do not develop the structures as well as fine-grained clastic units, however. In most rock units, a well developed \( S_1 \) cleavage is found which, in places, is axial planar to tight to isoclinal folds. Bedding and \( S_1 \) cleavage are generally parallel, except in the hinges of rare \( D_1 \) folds. In many locations, \( S_1 \) is gently north dipping, coincident with \( S_1 \) orientations in the overlying Kayak Shale of the Blarney
Creek duplex. $D_2$ and $D_3$ structures have the same orientations as their counterparts in the Blarney Creek duplex.

Within the Apon duplex, structural relations are a little more complex, but the same relations exist. $D_1$ structures do not show the same degree of variability between north and south dips as do those observed in the Blarney Creek duplex. For the most part, the axial surfaces of $D_1$ folds and their associated axial-planar cleavage have moderate to steep southeasterly dips throughout the Apon duplex. Bedding, where recognizable, is transposed into the $S_1$ foliation and fold axes are consistently southeasterly plunging. Only a few occurrences of north-dipping $D_1$ fabrics are preserved in the Apon duplex. These are found along the northern flank of the Doonerak window, just below the Blarney Creek duplex, where the horses of the Apon duplex merge smoothly into the overlying roof thrust (Blarney Creek thrust zone). Often, $S_1$ cleavage and $D_1$ folds in the Apon duplex, including those synclines cored by the Kekiktuk Conglomerate, are truncated by the Blarney Creek thrust zone, resulting in a high-angle discordance between members of the same generation of structures. $D_2$ and $D_3$ structures within the Apon duplex have the same orientations as those found in the overlying structural units.

As briefly outlined earlier, and discussed elsewhere (Handschy, 1993b; Phelps, 1993), rocks of the Endicott Mountains allochthon hanging-wall assemblage exhibit similar internal structural fabrics as those seen in the Doonerak footwall assemblage. $D_1$ structures in the Endicott Mountains allochthon vary between north and south dips in accordance with position around the Doonerak window. The basal thrust of the Endicott Mountains allochthon, the Amawk thrust, is folded by the east plunging, east-northeast trending Doonerak antiform, which is a $D_2$ fold. $D_2$ and $D_3$ mesoscopic structures have the same orientations on both flanks of the Doonerak window.
Clearly, since its basal thrust is folded by $D_2$, emplacement of the Endicott Mountains allochthon preceded $D_2$, which probably formed as the last stage of Doonerak multiduplex development (Avé Lallemant and Oldow, 1993). Imbrication of the footwall duplexes and formation of the Blarney Creek thrust zone also predated $D_2$ deformation because $D_2$ structures are consistently oriented throughout the duplexes, and have not been reoriented by later deformation. Thus, imbrication of both the Blarney Creek and Apon dupplexes of the footwall assemblage occurred during the first phase of deformation.

Additional constraints for the relative timing of footwall deformation are derived from the relations between imbricate horses and bounding faults, and among $D_1$ structures in the Blarney Creek and Apon duplexes and the Blarney Creek thrust zone. Although rarely, horses in the Blarney Creek duplex are decapitated by the Amawk thrust, implying displacement occurred on the roof thrust after subjacent horse imbrication. Likewise, the bottom of the Blarney Creek thrust zone truncates and removes substantial sections of horses $H_1$ and $H_4$ of the Apon duplex. The offset segments of decapitated Apon horses are not observed in the field area, indicating significant displacement on the roof thrust after horse imbrication. The top of the Blarney Creek thrust zone also removes section from the bottom of the Blarney Creek duplex, placing Lisburne Group directly on the Apon assemblage. Recurrent motion on roof and floor thrusts is also indicated by truncation of $D_1$ structures in upper and lower plate positions. Furthermore, the development of $D_1$ folds at the depositional interface of the Kekiktuk Conglomerate and the Apon assemblage before or during displacement within and along the Blarney Creek thrust zone is documented by the few preserved synclinal hinges below the Blarney Creek thrust, and the presence of corresponding $D_1$ fold limbs.
within the fault zone in which sheets of Kekiktuk Conglomerate exhibit subparallel bedding and S₁ cleavage.

Given the structural and stratigraphic constraints outlined above, two end-member models for footwall duplex formation are explored. In both models for the Doonerak multiduplex, imbrication is related to the emplacement of the overlying Endicott Mountains allochthon and subsequent collapse of its footwall. In a serial model (Fig. 21), the first step involves detachment between the Kayak Shale and autochthonous Kekiktuk Conglomerate to form the Blarney Creek duplex. During imbrication of the Blarney Creek duplex, Kayak Shale and Lisburne limestone are shortened to produce numerous horses. Younger clastic rocks (Sadlerochit Group, Shublik Formation, etc.) presumably were entrained at the base of the Endicott Mountains allochthon or were stripped from the top of the Lisburne during passage of the leading edge of the upper plate over the footwall ramp. During this stage of the serial model, all rocks beneath the floor of the Blarney Creek duplex remain autochthonous. The inception of D₁ folding of the Kekiktuk Conglomerate may have occurred during this stage, but large scale development of recumbent folds of the Kekiktuk would not be likely, because such substantial deformation of the Kekiktuk would require its detachment from the underlying Apoon assemblage.

At this stage of development, the serial model encounters fatal difficulties. If the Kekiktuk Conglomerate and the underlying Apoon were essentially autochthonous during imbrication of the overlying Blarney Creek duplex, they would come to lie behind the advancing tail of the most distal horse of the Blarney Creek duplex (Fig. 21). Subsequent involvement of the rocks composing the Blarney Creek thrust zone and the Apoon duplex would yield a footwall multiduplex geometry unlike that observed in the Doonerak window.
Figure 21. Serial kinematic model for development of the Doonerak multiduplex. The first step involves emplacement of the Endicott Mountains allochthon above the ramping Amawk thrust. Following this, the Blarney Creek duplex is imbricated while the Kekiktuk Conglomerate and Apoon assemblage remain autochthonous. Finally, the Apoon duplex is imbricated after imbrication in the overlying Blarney Creek duplex has ceased. The serial model fails because it produces an unobserved "prong" of Kekiktuk Conglomerate between the Endicott Mountains allochthon and the Apoon duplex hindward of the Blarney Creek duplex. See Fig. 7 for explanation of symbols.
A model invoking simultaneous development of the footwall duplexes (Fig. 22) better accounts for the relations observed in the Doonerak window. In this scheme, the Blarney Creek thrust zone acted simultaneously as an independent structural unit, and as the floor thrust to the Blarney Creek duplex, and as the roof thrust to the Apoon duplex. The omission of the Blarney Creek duplex on the southern flank of the Doonerak window and stripping of post-Lisburne strata, nevertheless, require some degree of sequential development, at least in the early stages of the multiduplex history. Regardless, during $D_1$ deformation, shortening in the footwall was partitioned among three simultaneously developing decollement systems: the Amawk thrust, the Blarney Creek thrust zone, and the unexposed floor thrust of the Apoon duplex. Truncation of horses beneath the Amawk thrust and at the base of the Blarney Creek thrust zone indicates recurrent motion on both thrusts. The rates of displacement on the different faults are unknown and could have been variable both temporally and spatially.

CONCLUSIONS

Typical models do not accommodate the geometry or kinematic development of the Doonerak window duplex beneath the Endicott Mountains allochthon of the central Brooks Range fold and thrust belt. The duplex does not contain a single roof and floor thrust system but rather is composed of two stacked subsidiary duplexes (the Blarney Creek and Apoon duplexes) that are separated by a shear zone called the Blarney Creek thrust. The Doonerak duplex, which formed during footwall collapse beneath the Amawk thrust underlying the Endicott Mountains allochthon, is a multiduplex whose stacked components developed simultaneously. Strict adherence to a serial kinematic model of deformation cannot account for observed structural relations. Rather, the stacked duplexes must have been
Figure 22. Simultaneous kinematic model for development of the Doonerak multiduplex. The first step, as in the serial model, involves emplacement of the Endicott Mountains allochthon above the ramping Amawk thrust. Following this, imbrication of the Blarney Creek duplex and the underlying Apoon duplex, and shortening of the intervening detached boundary layer, all occurs simultaneously, producing the observed geometry of the Doonerak multiduplex. See Fig. 7 for explanation of symbols.
imbricated at the same time. The Amawk thrust was employed as the roof thrust to the Blarney Creek duplex, while the Blarney Creek thrust zone served both as the floor thrust for the overlying Blarney Creek duplex and as the roof thrust of the underlying Apoon duplex. During duplex imbrication the roof thrusts were not progressively locked. Contemporaneous displacement on the Amawk and Blarney Creek thrusts is indicated by omission of structural section and truncation of horses of the Blarney Creek and Apoon duplexes.

The Blarney Creek thrust zone played a pivotal role in the development of the Doonerak multiduplex. The character of the fault zone varies along strike from a sharp structural contact between the upper and lower duplexes to a broad zone of distributed shear up to 250 m thick. The fault zone typically contains deformed conglomerate and occasional slices of upper-plate and/or lower-plate rocks. The presence of the Kekiktuk Conglomerate, which originally was deposited as a thin, probably discontinuous layer (averaging 5 to 20 m thick) at the interface between Devon-Carboniferous rocks and underlying lower Paleozoic strata, determined the location of the Blarney Creek thrust zone. The floor thrust of the Blarney Creek duplex formed in shale overlying the conglomerate, concurrently with detachment of the conglomerate from the underlying lower Paleozoic rocks to form the roof thrust of the Apoon duplex. During shortening and development of the adjacent duplexes, the Blarney Creek thrust zone maintained its structural integrity and the conglomerate was not generally incorporated into overlying and underlying structural units.
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