Fault tectonics in the Rapid depression of the Yukon North Slope (Canadian Arctic) - Summary of preliminary results

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ABSTRACT

Mesozoic to Tertiary rocks in the Rapid depression on the Yukon North Slope are dissected by a N-NNE striking fault array. Two phases of Tertiary deformation are recorded from the Barn uplift eastwardly across the Rapid depression. D_1 is characterized by strike-slip faults with either sinistral or dextral displacement in the depression and reverse-dextral oblique displacement on the southern Barn fault, indicating broadly E-W regional contraction. In contrast, D_2 deformation is somewhat more complex with first-order faults in the Rapid depression inferred to be primarily sinistral, while the southern Barn fault maintained its reverse-dextral oblique displacement. The structural style is inconsistent with the propagation of a large-scale strike-slip fault zone such as the Kaltag fault through the Rapid depression, as previously suggested, but rather may indicate reactivation of older structural heterogeneity in the subsurface.

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INTRODUCTION

In northernmost Yukon (Canadian Arctic), south of the Beaufort Sea, there is a wide area known as the Yukon North Slope. The Rapid depression (Fig. 1), in the eastern part of the Yukon North Slope, is a broad trough predominantly underlain by Mesozoic sedimentary rocks. It is flanked to the west by structural culminations of the Barn and Romanzof uplifts and to the east by the Aklavik arch complex (including Rat, Scho, White and Cache Creek uplifts; Fig. 1; Norris, 1997); Paleozoic and locally older rocks are exposed in both regions. Mesozoic rocks of the Rapid depression straddle the boundary between the Paleozoic North American continental margin in the east and Arctic Alaska terrane in the west. Mesozoic and locally Tertiary rocks in the depression are cut by a swarm of N-~NNE striking faults which occur in a north-south corridor ~60 km wide (Rapid fault array; see Norris and Yorath, 1981; Norris, 1997).

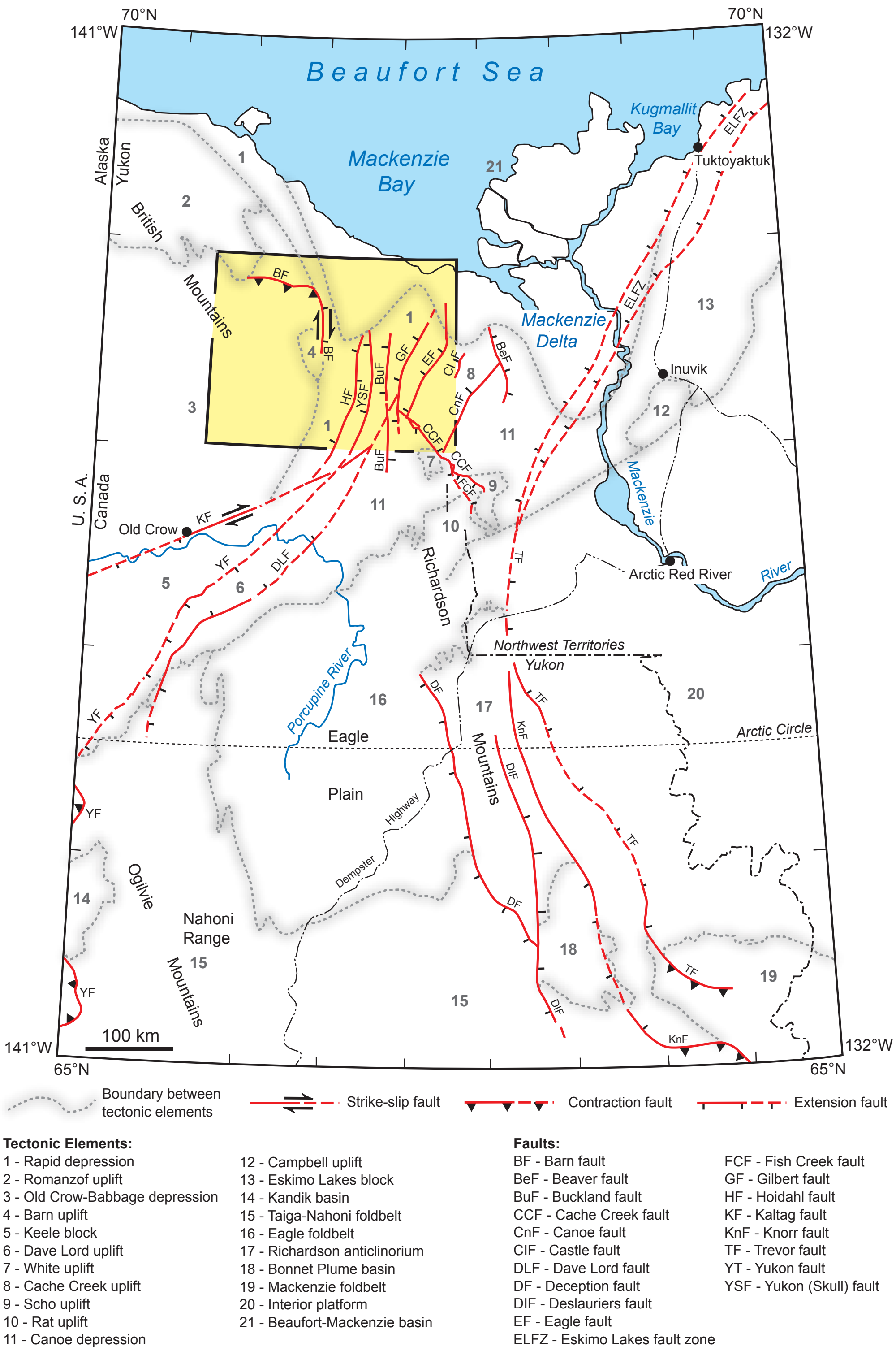

Figure 1. *Tectonic elements and main faults in northern Yukon and adjacent Northwest Territories, Canada (map modified from Norris, 1997). Frame with yellow fill shows location of the map of the study area (Fig. 3). Note that the extension of the Tertiary, strike-slip Kaltag fault into Yukon is called into question here and in Lane (1992).*

Structural information from the depression is critical to reconstructing the nature of interactions between Arctic Alaska and the northwestern North American margin in late Mesozoic and Tertiary. Furthermore, these data might give insight into the plate tectonic significance of the faults and related structures and answer the question of whether the tectonic development in the Rapid depression can be geometrically and kinematically linked to the Eurekan deformation in the Canadian Arctic Archipelago, North Greenland and Svalbard (compare, for example, Balkwill, 1978; Kerr, 1981; Tessensohn and Piepjohn, 2000).

PREVIOUS WORK

The Rapid depression has been inferred to be the locus of the continuation of the Kaltag fault, a major ENE-WSW dextral strike-slip fault defined in western and central Alaska (*cf.*, Norris, 1976, 1981, 1997; Fig. 1). Although the Kaltag fault has been included in Cenozoic plate tectonic reconstructions of the Arctic (*e.g.*, Jones, 1980; McWhae, 1986), it appears restricted to the western and central parts of Alaska (*e.g.*, Grantz, 1966; Patton and Hoare, 1968; Patton 1973; Fig. 2). Lane (1992) argued against its along-strike continuation into northern Yukon.

Deformation in the Rapid depression has been characterized as a Paleocene-Eocene fold-and-thrust belt, lacking regionally important strike-slip faults (Lane, 1988). This belt continues northward into major fold structures of the arcuate Beaufort fold-and-thrust belt offshore in the southern Beaufort Sea (*e.g.*, Lane, 1998; Fig. 2). Several interpretations of seismic lines from these offshore areas have shown that the arcuate belt was mainly formed during the Paleocene-Eocene but youngs towards its outboard northern and eastern parts (compare, for example, Dietrich *et al.*, 1989; Lane and Dietrich, 1991; Lane, 1998, 2002; Dixon *et al.*, 2001; Dinkelman *et al.*, 2008; Helwig *et al.*, 2011).

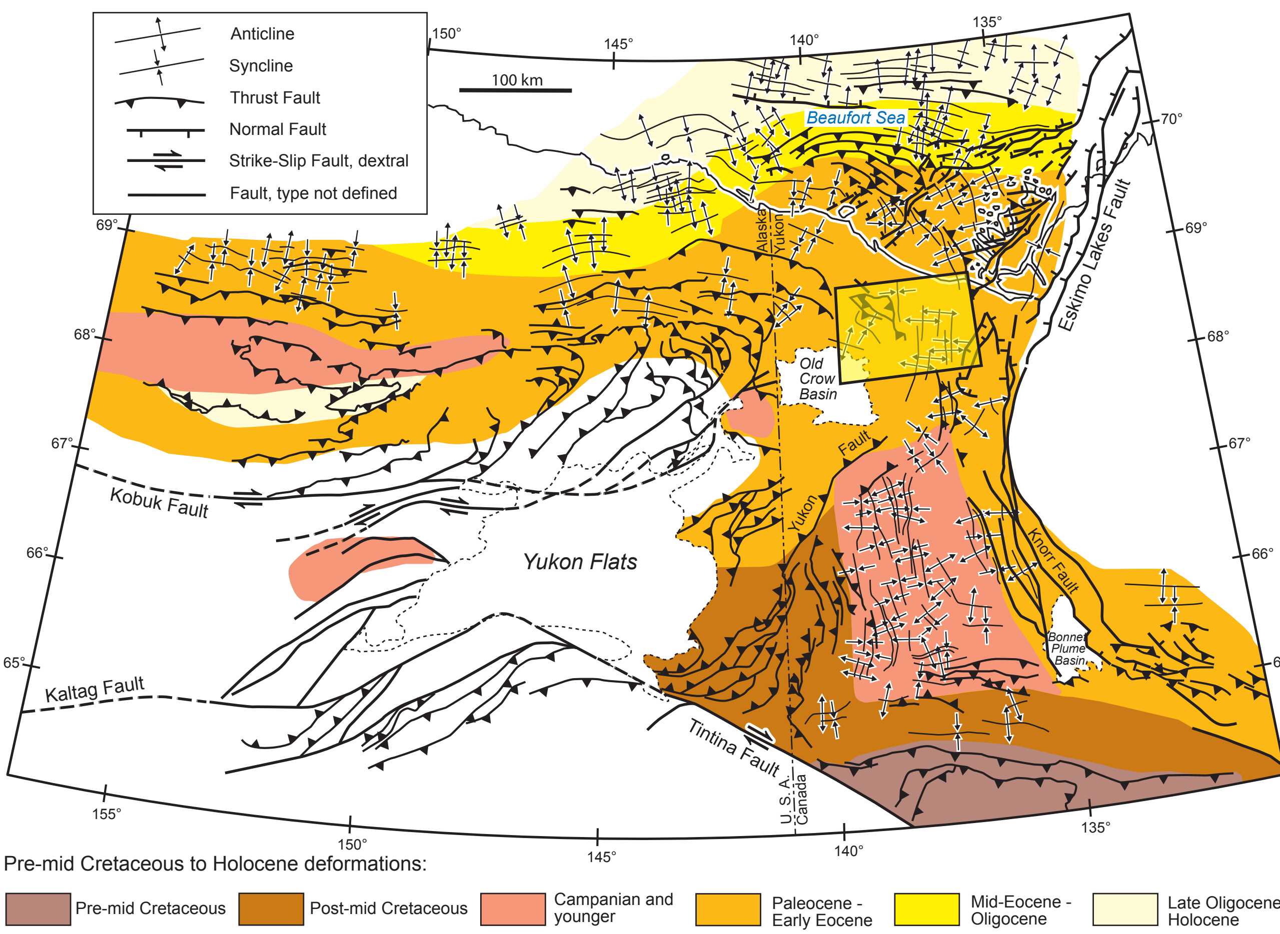

Figure 2. *Simplified tectonic map of northeastern Alaska, northern Yukon, and adjacent Northwest Territories (Canada) showing the trends of major Late Cretaceous-Tertiary structures and approximate ages of pre-mid Cretaceous to Holocene deformations (modified from Lane, 1998, 2002). Frame with yellow fill shows location of map in Figure 3.*

GEOLOGIC SETTING OF THE RAPID DEPRESSION

The Barn uplift, partly bounding the western edge of the Rapid depression (Figs. 1 and 3), consists of Neoproterozoic to lower Paleozoic (meta-)clastic and carbonate rocks intruded by granitic plutons of Late Devonian age (Lane, 2007), all part of the Arctic Alaska terrane. The pre-Carboniferous succession is folded and dissected by several east-directed thrust faults (Cecile, 1988; Cecile and Lane, 1991; Dyke, 1997). The first phase of deformation in the core of the Barn uplift has been interpreted as post-Late Silurian to pre-Early Carboniferous (Cecile, 1988) or Middle-Late Devonian (Dyke, 1997); it is inferred to be related either to the Ellesmerian Orogeny or to the Romanzof Orogeny (Lane, 2007). The Barn uplift is bounded on the east by the Barn fault. In the north, west, and south, the rocks in the uplift are unconformably overlain by Carboniferous and younger clastic deposits (Fig. 3).

The Rapid depression and areas surrounding the Barn uplift are underlain by Jurassic to Upper Cretaceous, and locally Tertiary clastic deposits (Fig. 3). The eastern margin of the Rapid depression, in the Richardson Mountains, consists of upper Paleozoic deposits overlain by Mesozoic rocks in the White and Cache Creek uplifts (Figs. 1 and 3).

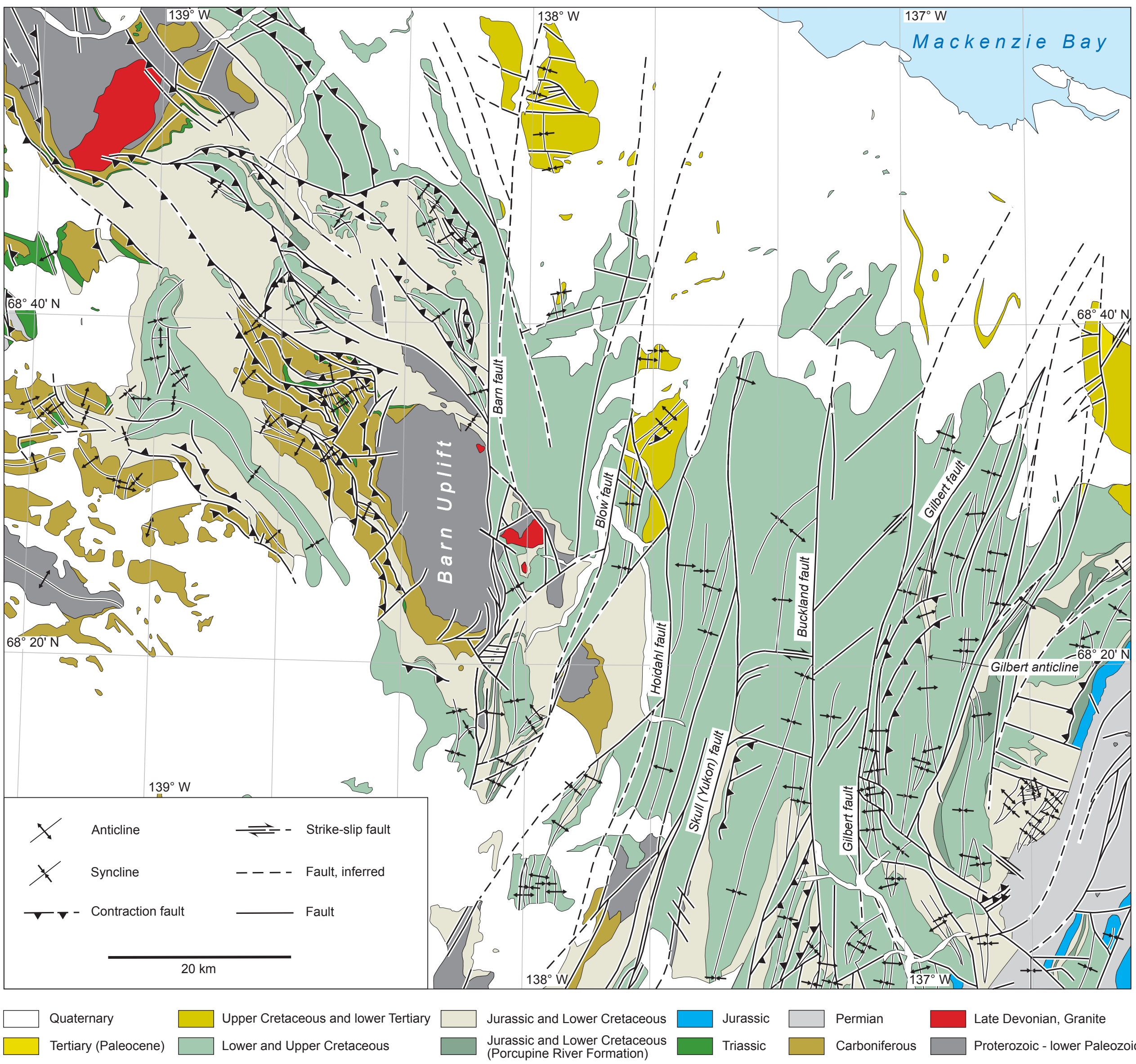

Figure 3. Simplified geological map of the Rapid depression and adjacent areas (north Yukon, Canada) modified from Norris (1981). For location see Figures 1 and 2.

FAULTING IN THE RAPID DEPRESSION

From west to east the major faults in the Rapid depression are as follows (Norris, 1981, 1997; Fig. 3):

(1) The N striking Barn fault separates the Barn uplift to the west from Cretaceous rocks of the Rapid depression to the east. Its northern continuation cuts through Cretaceous rocks and, farther northwards, turns to the northwest and west. To the east of the southern segment of the Barn uplift, two faults, striking NW and NE, separate pre-Mesozoic rocks from Jurassic and Cretaceous deposits.

(2) The NNE striking Blow fault cuts Jurassic to Tertiary rocks and possibly older rock of the Arctic Alaska terrane in the south.

(3) The NNE striking Hoidahl fault (new name, replacing the name 'Kaltag fault' on the map of Norris, 1981) affects Cretaceous rocks in its central and northern segments but displaces lower Paleozoic and/or older rocks of Arctic Alaska terrane in the south. Norris (1981) interpreted this fault as the northeast extension of the Kaltag fault from Alaska; however, following Lane (1992) this correlation appears unlikely and therefore the name Hoidahl fault is proposed here for this structure.

(4) The NNE to N striking Skull (Yukon) fault cuts mostly Cretaceous rocks and in the south also cuts lower Paleozoic rocks of Arctic Alaska terrane. East and southeast of Old Crow, the Yukon fault strikes NE (Fig. 1; Norris, 1981) and also affects Proterozoic, Cambrian to Devonian, and upper Paleozoic rocks of North American affinity. From there, it continues farther south with a NNE strike (Journeay *et al.*, 2000).

(5) The N striking Buckland fault cuts Cretaceous rocks in the north and Jurassic rocks in the south.

(6) In the north, the Gilbert fault has a NNE strike and cuts Cretaceous rocks; its strike changes to a N strike in the south. Farther south, it ends directly north of NNE trending folds in Cretaceous rocks (compare Norris, 1981; present Fig. 3). The Gilbert fault is accompanied by several faults and folds to the east.

Most faults in the Rapid depression have a N to NNE strike. The curved Barn fault is an exception (Fig. 3). Additional NW striking reverse faults, affecting Carboniferous but mostly Jurassic and Cretaceous rocks, occur west and north of the Barn uplift (Fig. 3; Norris, 1981). All faults in the region cut Cretaceous rocks and are therefore Cretaceous or younger.

STRUCTURAL OBSERVATIONS RELEVANT TO FAULT KINEMATICS

The major faults and their damage zones are rarely exposed. This study examined exposures as close to the traces of major faults as possible in order to interpret the fault kinematics. Field observations were then combined with major folds and faults mapped by Norris (1981) to synthesize the overall geometries and relations between the sense of fault displacement and adjacent structures. This synthesis led to a reinterpretation of the sense of displacement for some of these faults compared to those inferred by Norris (1981).

Structural measurements related to D_1 deformation supported an interpretation of kinematics at every study location. The shortening orientations near the faults were used to interpret their sense of displacement during first-stage deformation. Shortening orientations during D_1 deformation for each location were determined based individually or collectively on orientations perpendicular to the maxima of B_1 fold axes, δ_1 intersection lineations, and/or girdles through poles of bedding planes.

D_1 DEFORMATION

All Jurassic to Tertiary clastic sedimentary sequences are affected by a D_1 deformation. Open, N to NE trending F_1 folds measure anywhere from a decimetre to more than 100 m and are typically symmetrical, chevron-like structures; however, folds can display either ~E or W vergence. The large Gilbert anticline in the eastern part of the Rapid depression is a good example of an F_1 structure with a N trending axis (Fig. 3). The folds are accompanied by S_1 fracture cleavage with spatially variable intensity. Tertiary sandstones east of the Blow fault display an incipient S_1 fracture cleavage. These rocks are affected by a map-scale, broad, open F_1 syncline with a ~NE trending axis (Fig. 3). Local reverse faults in the Mesozoic succession represent accommodation faults related to F_1 folding. The general picture suggests a ~E to SE contraction direction during the D_1 deformation east of the Barn fault.

In this study's interpretation, the southern, N striking segment of the Barn fault represents an oblique dextral fault with an east-directed reverse component. This segment has been interpreted as a right-lateral fault with 10 km of displacement (Norris, 1997, p. 56) and a minimum vertical separation of approximately 300 m (Dyke, 1997, p. 341). In its northern NW to W striking segment, the Barn fault was interpreted as a thrust fault (Norris, 1981, 1997). This reverse sense is also supported by the data collected in this study and the NW strike of reverse faults along this segment of the hanging wall.

The Blow fault is interpreted as a sinistral strike-slip fault based on the NW-SE contraction related to development of a F_1 syncline in Tertiary clastic rocks to the east. However, based on the stratigraphic successions preserved on either side of the fault, Young (1974, p. 295) reported that the west side was displaced upward relative to the east side during three main episodes of Early Cretaceous deformation.

For the Hoidahl and Skull (Yukon) faults in the east a sinistral displacement is proposed. On the latter, 5 km of left-lateral separation was reported by Norris (1997, p. 57).

The Gilbert fault, in the eastern side of the Rapid depression, can be interpreted as a dextral strike-slip fault with related F_1 folding to the east (Gilbert anticline). There, the axes of spatially associated folds are obliquely oriented at a small angle with respect to the Gilbert fault and other parallel dextral fault lines (Fig. 3). To the south, the N-S oriented branch of the Gilbert fault is interpreted as a reverse fault, possibly with a dextral component. The southern termination of this fault is within Cretaceous clastic rocks.

It should be emphasized that all faults with lateral displacements during this first stage of deformation are not interpreted as pure strike-slip faults. It is more reasonable to suggest that displacements were accompanied by varying reverse components during fold-and-thrust belt deformation.

The overall shortening, shown by the open F_1 folding and partly continuous trends of folds in the clastic succession, argues for a detachment fault (or faults) in the subsurface. However, the depth, extent, and geometry of such a horizon (or horizons) remain unclear.

D_2 DEFORMATION

In the outcrops studied, the D_1 structural elements are crosscut by sets of younger brittle shear and fault planes. Their senses of shear and displacement are shown by slickensides and steps. The precise time difference to D_1 structures, however, is unclear. For the measured D_2 structural elements, the kinematic P (shortening) and T (extension) axes (Marrett and Allmendinger, 1990) and the fault plane solutions were calculated with the program FaultKin (version 6.5.0) of Allmendinger (2013).

D_2 deformation is best exemplified in the area of the Gilbert anticline and Gilbert fault (Fig. 3). There, the N trending F_1 Gilbert anticline is cross cut and displaced along NE striking and ~NW directed reverse faults which curve into a southern N-S oriented branch of either the Gilbert fault or a parallel fault (Fig. 3). A NW verging F_2 fold structure, which overprints S_1 cleavage planes and is floored by a detachment, was observed in the hanging wall of one of these reverse faults. Faults and shear planes with similar orientations and calculated P axes were also observed in the hinge zone of the Gilbert anticline, suggesting NNW-SSE contraction across this region during D_2 deformation.

Overall, the calculated D_2 P axes and fault plane solutions for structures in the Rapid depression east of the Barn fault range from E-W to NW-SE to N-S. NW-SE axes predominate near first-order faults indicating a sinistral to sinistral-oblique reverse displacement; N-S axes and E-W axes occur at outcrops between first-order faults, the former especially along second-order reverse faults that are kinematically compatible with sinistral offset along first-order faults. The primarily NW-SE sense of contraction caused a reactivation of older (D_1) strike-slip faults with the same or opposite strike-slip motion relative to the previous displacement. An instructive example is the Gilbert fault and areas to the east (Fig. 3). This study's data from the Gilbert fault have shown that after its first dextral stage with related folding (see above), the sense of displacement changed to sinistral strike-slip along the N trending fault segment and northward. In the south, however, the fault ends in folded Cretaceous rocks with ~NE trending fold axes. This observation suggests that displacement, during both D_1 and D_2, transferred onto another fault, thereby avoiding the sedimentary succession at the south end of the Gilbert fault. This argues for strike-slip faulting in limited segments, probably caused by inherited older and reactivated structures in the subsurface (see below).

All other faults to the west of the Gilbert fault are interpreted as sinistral strike-slip faults, combined with a reverse component, and partly changing into reverse faults along strike during D_2. The sense of displacement along the Hoidahl fault, however, remains unclear. In the west, the N-S oriented section of the Barn fault seems to have remained active as an oblique, dextral fault.

INTERPRETATIONS AND CONCLUSIONS

The structural geometry and kinematic evolution reported here provide argument against a simple high-level fold-and-thrust belt within the Rapid depression. Fold axes that are oblique with respect to many fault lines, suggest that folding occurred concurrently with strike-slip movements. The entire picture, however, does not support a large-scale, uniform, strike-slip dominated regime. If it were an overall regime of strike-slip tectonics, a single sense of shear, either dextral or sinistral, would be expected. Instead, this study interprets two stages of fault tectonics with different sense of displacements and a more complex tectonic history during the early Cenozoic. There is no evidence for a through-going and significant Tertiary strike-slip fault, such as the Kaltag fault, that could be interpreted as an intracontinental displacement zone of plate tectonic significance.

The precise age of the clastic Tertiary deposits in the Rapid depression, affected by both stages of deformation, is unclear. It can only be stated that they are Paleocene. It is assumed that the first-stage deformation (D_1) is Paleocene or Eocene in age (see also Lane, 1988, 1998, 2002; compare with Fig. 2) whereas the second stage (D_2) might be Eocene and/or younger. Therefore, both phases of deformation seem to have taken place during the time of Eurekan deformation in the Canadian Arctic Archipelago (*e.g.*, Balkwill, 1978; Tessensohn and Piepjohn, 2000; von Gosen *et al.*, 2012; Piepjohn *et al.*, 2013) and postdate the Cretaceous opening of the Amerasia Basin.

It seems reasonable that strike-slip faulting and their present surface expressions were caused by structural heterogeneities in the subsurface. As the area under discussion represents the western marginal part of the North American craton to the east, and has been affected by pre-Mesozoic (Monger and Price, 2002) or younger (O'Leary *et al.*, 1995; Lane, 1998) extension and rifting, older and rift-related (normal) faults could have been reactivated during Tertiary compressional faulting and folding. They might have led to the development of the observed strike-slip faults. Reverse faulting and parallel dextral and sinistral faults in the Rapid depression during D_1 deformation support this interpretation.

The Eskimo Lakes fault zone is a possible candidate for a structure of plate tectonic significance (Figs. 1 and 2). It continues offshore towards the northeast into the Beaufort Sea and possibly defined the former margin of the North American craton. Arcuate bending of the Tertiary structures occurs to the west and northwest of this fault zone. This might suggest that faulting and folding were contemporaneous events and the Eskimo Lakes fault zone accommodated crustal shortening by dextral strike-slip. Bending of the structures in the northeast Alaskan area, however, might have been accommodated by the dextral Kobuk fault to the south (Fig. 2) and not the Kaltag fault.

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