CHAPTER 3 STRUCTURE

Although the stratigraphy of the project area suggests periodic extensional or contractional tectonism between Late Proterozoic and middle Paleozoic time, intense eastward compression during the late Mesozoic produced the dominant structural fabric. This structural style is dominated by thrusting and/or folding and is part of several major fold and thrust structural provinces (Rocky Mountain and Selwyn, Figure 8) that together extend along the entire eastern margin of the North American Cordillera. Folding and thrusting are inter-related; most thrusts carry detached anticlines, generally with overturned strata in the hangingwall.

The character of fold and thrust deformation changes from north to south within the study area, due to the change in the overall composition of the stratigraphic sequence. In the south, the presence of thick sections of competent Cambrian carbonate and quartzite results in a structural style dominated by imbricated thrust panels. The northward disappearance of these competent lithologies results in folding and penetrative cleavage becoming the dominant structural elements throughout the remaining part of the map area.

Although these previous statements are broadly correct, the apparent dominance of folding in the area north of Horneline Creek may be oversimplified and, may be a reflection of the relatively poor exposure and lack of marker horizons. The density of data points in this region is less than half of that to the south. As a result, a fairly conservative interpretation has been applied to the map and cross-sections. The structural interpretation favours upright to northeast-verging folding. The implications of this are that the extent of thrust faulting may be underestimated, particularly within the large expanse of monotonous Road River rocks south of Chee Mountain and within Kechika rocks north of Graveyard Lake.

Thrusts are by far the most dominant of the numerous faults recognized within the study area. Steep normal or reverse faults, although rarely documented south of Terminus Mountain, are delineated in several areas north of Horneline Creek, particularly along the western part of the map area. The Northern Rocky Mountain Trench strike-slip fault is the only example of this type recognized with certainty in the map area, but its significance, from a tectonic and geomorphological viewpoint, cannot be understated.

THRUST FAULTS

Thrust faults recognized within the map area are all northeasterly directed. Most of them trend northwesterly, with only the Chee Mountain and related thrust faults having a more northerly strike. The average length of these faults is approximately 15 kilometres with the longest being traceable for over 40 kilometres (Netson Creek thrust fault). The dip of the faults at surface, as observed in outcrop and inferred from cross-sections, is normally steep to very steep. The only exceptions to this are at the base of klippen of Cambrian carbonate southeast of Terminus Mountain and along Boya Hill where drill holes intersected a flat-lying thrust several hundred metres below surface (Moreton, 1984). This fault may connect southward across Boya Creek with a thrust along Chee Mountain, suggesting that it is also very shallow or that dip decreased to the north.

The relatively flat thrust carrying klippen of Cambrian carbonate above Silurian siltstone near Terminus Mountain

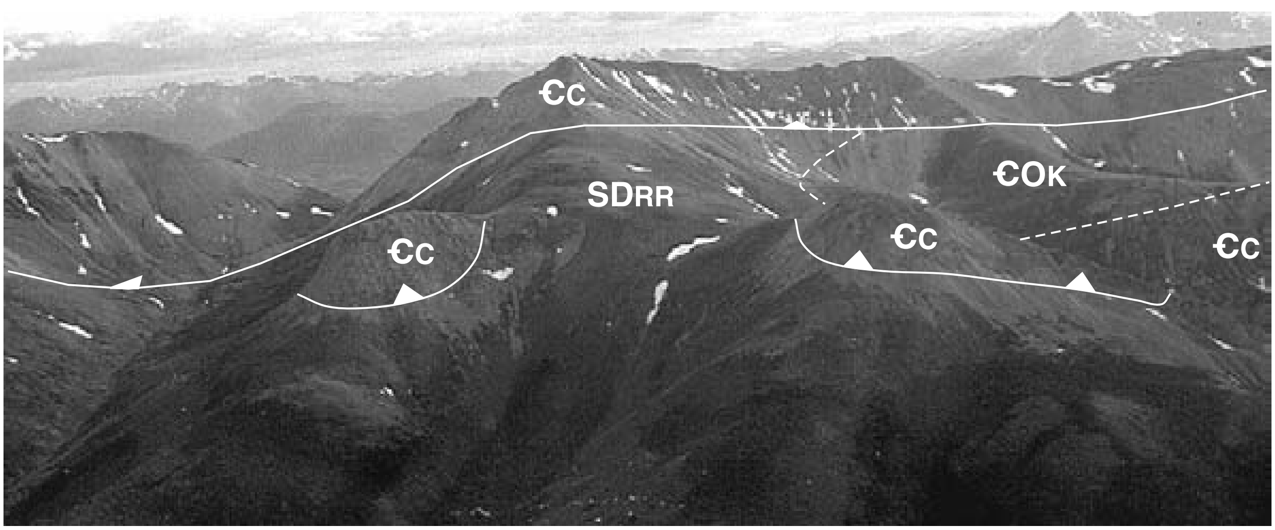

Photo 51. Looking west at klippe of Єc carbonate sitting above argillite and dolomitic siltstone of the Road River Group, about 5 kilometres southeast of Terminus Mountain. The Gataga Mountain thrust fault is approximately 1 kilometre to the west and carries overturned Єc carbonate in its hangingwall. The klippe, together with the underlying sediments, has been folded after being emplaced. Structural cross-sections suggest that the fault carrying the klippe is probably younger than the Gataga Mountain thrust.

(Photo 51) is probably not part of the Gataga Mountain thrust fault, because this would require the existence of a large nappe, which was later tightly folded. The most likely explanation is that the klippen are remnants of an earlier thrust panel or horse that formed ahead of the Gataga Mountain thrust.

Although many of the thrust faults are steep to near vertical, steep bedding dips are common in hangingwall strata, indicating the faults are parallel to sub-parallel to layering. This is particularly well displayed by cross-sections within the Cambrian carbonate sequence in the southern part of the map area. The present steep orientations of some strata and faults probably resulted when later compression imbricated and folded the stratigraphic sequence. This process may have led to the rotation of earlier structures and may explain the southwest vergence of folds and northeast dip of cleavage within Road River and Earn stratigraphy north of Split Top Mountain (*see* section B-B').

Major thrust faults in the map area carry Cambrian or uppermost Proterozoic strata in their immediate hangingwalls (Photos 52 and 53). Stratigraphic displacement on some of them, such as the Gataga Mountain and Split Top Mountain thrusts, ranges to more than 1000 metres. Absolute amounts of movement on different faults vary considerably and are based on interpretive cross-sections (A to G) and their extrapolation to depth. Movement on the Netson Creek, East Split Top and Gataga thrusts is probably in the order of 5 kilometres. Displacement on individual faults carrying slivers of Єc in the south (*see* western parts of sections B - B', C - C' and D - D') is unconstrained, but probably of similar order. The Chee Mountain thrust appears to have an absolute displacement of between 3 to 5 kilometres (section G - G' and extrapolation northward). The Brownie Mountain thrust has probably moved only 1.5 to 2 kilometres, and movements on many of the other faults in the map area are probably of this magnitude.

Displacement on major thrusts is substantially larger than on individual thrust faults found higher in the stratigraphy of each thrust sheet. Displacement on some of the larger faults must have been transferred into a series of smaller scale thrusts and associated folds in their footwalls. This is well displayed east of the Split Top Mountain thrust where Earn and Road River strata are repeated by small-scale folding and faulting (Photo 54). Thrusts within Earn and Road River rocks probably extended downward into the Kechika Group and this displacement must feed into the larger thrusts carrying Cambrian stratigraphy.

In the far southern part of the map area, large thrust panels of Cambrian carbonate commonly sit on Kechika or lower Road River shales, suggesting they are an important zone of detachment. This probably reflects the low structural competency of these lithologies and their location between more rigid siltstones of the Road River Group and the carbonates and quartzitic rocks of the Cambrian succession. This geometry also implies that the upper part of the Cambrian siliciclastic package also acted as a zone of weakness within the Cambrian carbonate belt, probably as a result of its relative incompetence with respect to overlying carbonates. North of the Cambrian carbonate shale-out, thrusts carrying Cambrian or Road River siliciclastics typically occur above incompetent lithologies of the Earn Group.

McClay *et al*. (1988), working adjacent to the southern end of the map area, delineated an early, westerly directed thrust fault which carries Cambrian siliciclastics and carbonates in its hangingwall. This structure can be traced northward to the Gataga River, extending into the southeastern part of our map area, and should involve the most easterly panel of carbonate. No such structure was observed, suggesting that this early structure has either lost all displacement or has veered to the east, outside the study area.

NORMAL FAULTS

Although no steep faults of normal displacement were directly observed in the field, they are inferred from map-pattern geometry. The only significant examples are north and east of Split Top Mountain. They are north-trending, west-side-down structures affecting Cambrian carbonates and siliciclastics in the footwall of the Netson Creek thrust, and Earn and Road River rocks in its hangingwall. Vertical displacement is in the order of several hundred metres.

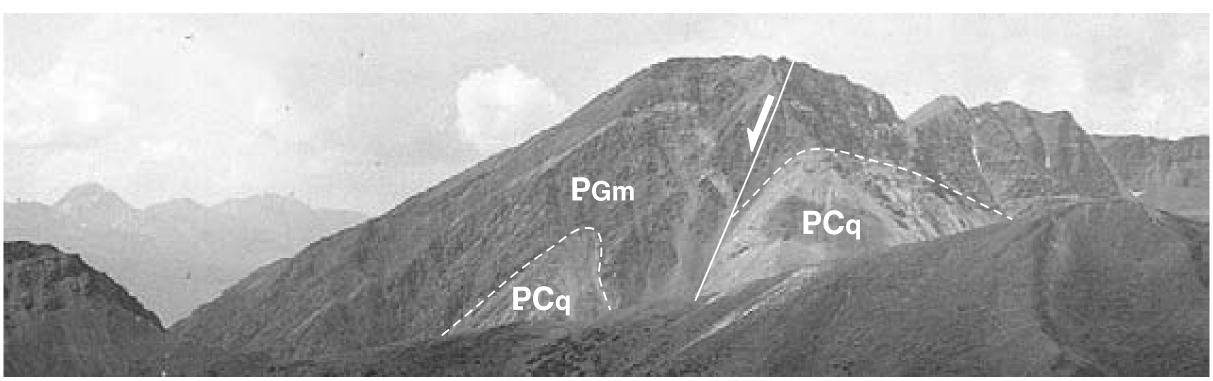

Photo 52. Looking north at Gataga Mountain. The structure of the Gataga Mountain anticline is particularly well outlined by the sediments of unit Pcq and a lighter coloured tuffaceous sediment horizon within the Gataga Volcanics (PGm). This structure must be cut by a late west-side-down normal fault, as shown here.

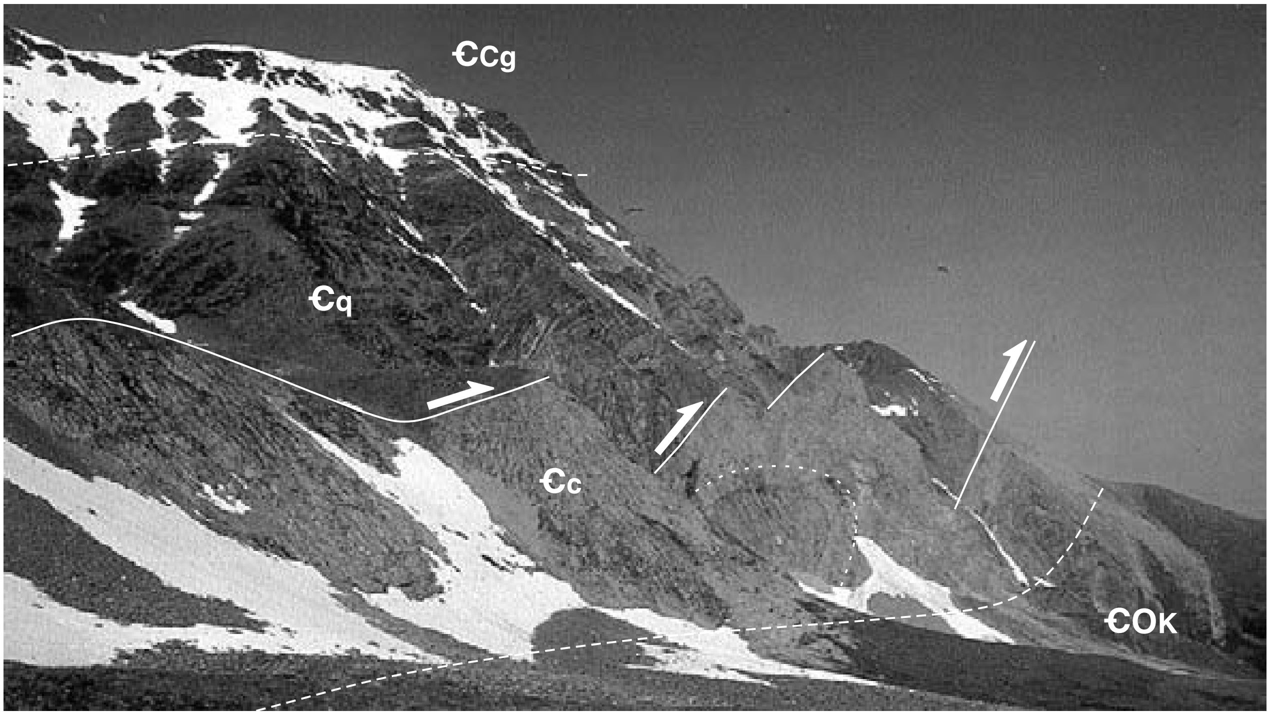

Photo 53. View to the north towards the east side of Brownie Mountain which shows Lower Cambrian quartzite of unit Єq and conglomerate of unit Єcg thrust over folded carbonate of Єc and calcareous argillite of the Kechika Group (ЄOK), both of which occur in the core of a northeasterly overturned syncline.

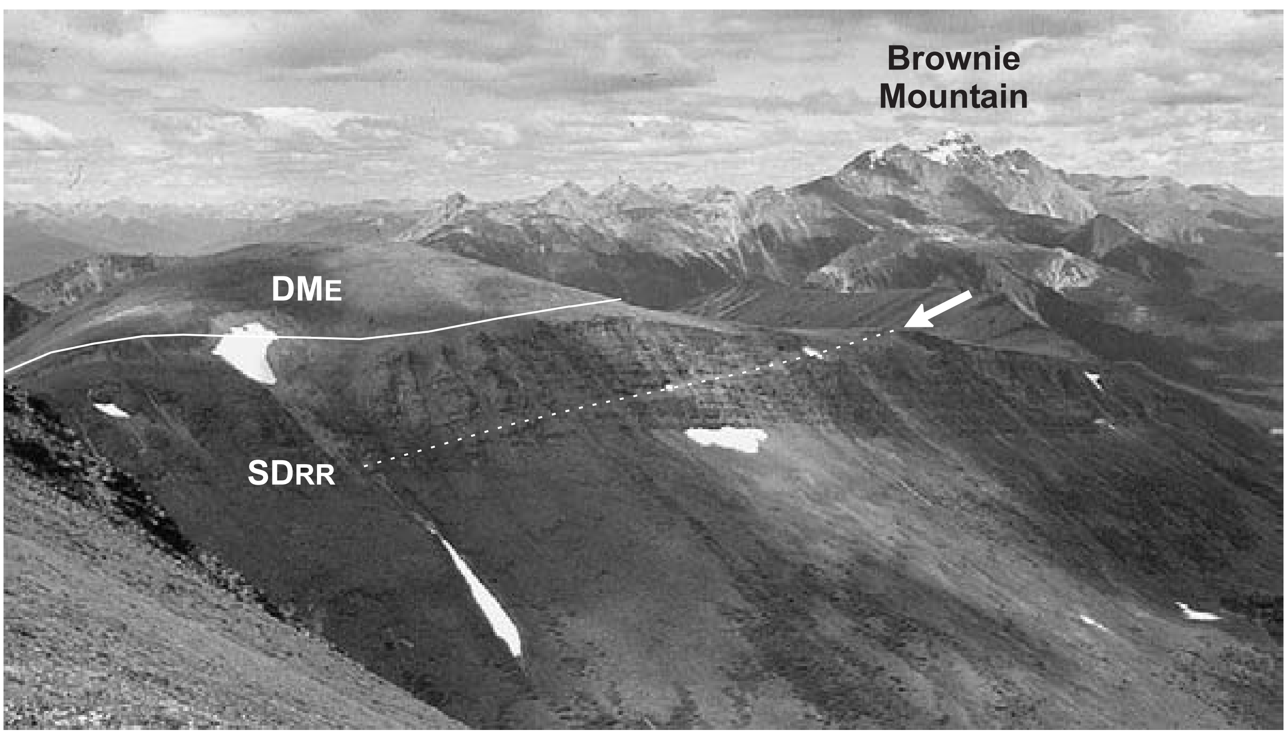

Photo 54. Looking north at a thrust panel of upper Road River dolomitic siltstones (SDRR), and argillites and slates of the Earn Group (DME). Bedding in the Road River siltstone sequence appears to be offset by a diagonal fault (thrust?) indicated by the arrow. This fault was not observed while traversing over the ridge due, in large part, to the monotonous nature of Road River lithologies.

Photo 55. Looking northwest along the Northern Rocky Mountain Trench from the western slopes of Gataga Mountain. The Kechika River can be seen in the valley bottom.

Photo 56. View to the south showing the northern termination of the Northern Rocky Mountain Trench. Terminus Mountain can be seen on the left of the photograph and the Cassiar Mountains in the background, across the trench. The observer is sitting on prominent hills within the Rabbit Plateau. Terminus Mountain is the last 'Rocky' Mountain along the northern end of this continental mountain belt. North of Terminus Mountain, the Northern Rocky Mountain Trench looses definition as it opens up into the Rabbit Plateau (as shown here) and is lost as a physiographic feature within the more northerly Liard Lowlands.

North of Horneline Creek normal faults are more significant in length and, to a certain extent, control the overall geometry of the map pattern. They trend northeasterly and are from 5 to 15 kilometres in length. Although not observed directly, the presence of these structures is supported by abrupt changes in geology across several prominent northeast-trending valleys, such as Horneline Lake, Graveyard Lake and several creeks to the north of here, Gemini Lakes and the northeast bend of the Kechika River. The faults are generally northwest-side-down and have displacements in the order of several hundred metres.

The fault along Graveyard Lake valley also delineates a boundary between two facies of the Kechika Group, which suggests it is a re-activated older, basin-controlling structure. These faults are roughly parallel to major faults Cecile *et al*. (1997) postulate influenced development of the western North American miogeocline during the early Paleozoic, particularly in this region, near the transition between the Kechika Trough and the Selwyn Basin.

NORTHERN ROCKY MOUNTAIN TRENCH FAULT

The Northern Rocky Mountain Trench fault takes its name from the great valley carved by the Kechika and Finlay rivers, and which, to the south, is now occupied by Williston Lake (Photos 55 and 56). This broad, well defined valley begins to lose expression north of Terminus Mountain and is essentially lost beyond the Red River, where it opens to the broad glacial-fluvial deposits of the Liard Plain. This northwest-trending structure is one of several major dextral faults of Late Mesozoic to Early Cenozoic age recognized along the length of the Canadian Cordillera (Gabrielse, 1985). It can be traced northwards into the Yukon where it links with the Tintina fault.

Only a few traverses near the headwaters of Calf and Mustela creeks crossed the inferred northward extension of the Northern Rocky Mountain Trench fault. In Calf Creek, sediments are brecciated and sheared and possibly mylonitized intrusive rocks outcrop along Mustela Creek. These exposures provide an approximate position for the fault, or its splays, in this region. Elsewhere on the Liard Plain, the position of the fault is virtually unconstrained and is very tentative. In the south, the location of the main fault is believed to be close to the lower, western slopes of the Kechika valley (H. Gabrielse, personal communication, 1996). A section of strongly sheared slates is exposed along the Turnagain River where it enters the trench (H. Gabrielse, personal communication, 1996). Strongly disrupted blue-black calcareous and noncalcareous slates and argillites exposed in scattered outcrops for several kilometres downstream from this location suggests there are splays off the main fault. These relationships suggest that fault motion is probably distributed over a wide zone as opposed to a discrete surface.

FOLDS AND CLEAVAGE

Many, if not all, of the thrust sheets in the map area are internally folded and have a penetrative or spaced cleavage in argillaceous lithologies. Folding played an equal or even greater role than thrust faulting in the overall structural development of the map area. Only one period of folding is apparent in most of the area. It is only in the Aeroplane Lake panel that the ubiquitous upright to northeast-verging folding and associated cleavage is seen to overprint an earlier phase of folding. This panel also exhibits the highest grade of metamorphism within the study area.

FOLDS

Fold styles in the study area reflect the composition of the affected rocks. On an outcrop scale, competent lithologies, such as carbonate and quartzite of units Ꞓc and Ꞓq, produce folds approaching parallel geometry, although they do have thickened hinge zones (Photos 57 and 58). These are probably Class 1C folds in the classification scheme developed by Ramsay (1967). They lack, or have a poorly developed, spaced cleavage. Thinly interlayered quartzite or quartz sandstone and slate commonly within unit Ꞓs display chevron-like fold shapes.

Incompetent lithologies, including shale, slate and calcareous shale, contain a pervasive cleavage and exhibit thickened hinges and thinned limbs, approaching the geometry of Ramsay's Class 2 type folds (Photos 59 and 60). Similar-type folds are by far the most common in the map area, reflecting the dominance of shaly lithologies and the grade of metamorphism. The ubiquitous slaty cleavage, which is locally phyllitic or schistose, reflects the relatively elevated temperatures and increased ductility of these rocks, compared to those in eastern parts of the Rocky Mountains.

Megascopic folds, which are generally upright to northeast-verging, are recognized throughout the map area. Folds with southwest inclinations were observed on the west flank of Split Top Mountain and to the east, within the upper part of the Netson Creek thrust panel. They are less than 5 kilometres long and are open to closed, with wavelengths up to 1 kilometre.

Northeast-verging folds are open to tight in the south and generally become more open northward. These folds vary from a few to over 10 kilometres in length and have wavelengths up to several kilometres. Many could not be recognized directly in the field but were inferred from either bedding attitudes or outcrop distributions. One such fold begins a few kilometres west of Netson Lake, in rocks of the Kechika Group, and can be traced northward some 40 kilometres to the latitude of Scoop Lake. It is open and upright with a wavelength of 1 kilometre in the south and over 5 kilometres in the north.

The thick carbonate successions of unit Ꞓc commonly delineate northeasterly overturned anticlines at the leading edges of thrust panels. Excellent examples of this are along the southwest side of Split Top Mountain and on the carbonate knoll east-northeast of Brownie Mountain (Photo 31). Apparently thick sections of Kechika and Ordovician shales in the south and southwestern part of the map area are probably the result of tectonic thickening in the cores of these larger scale folds, together with termination of thrust faults within this package.

Only a few large folds are exposed above tree line and clearly defined by contrasting lithologies or marker hori-

Photo 57. Parallel fold in thick quartzite layer in Cambrian siliciclastics exposed along the north shore of the lower Red River. Note that the less competent sediments above the anticline outlined by the quartzite layer have behaved more ductily, displaying a more similar fold style.

Photo 58. Open parallel folds developed in interlayered quartz sandstones, siltstones and slates of unit Ꞓs approximately 5 kilometres south of Netson Lake.

Photo 59. Modified parallel fold outlined by calcareous argillite and argillaceous limestone in the upper part of the Road River Group(?). This outcrop is at the mouth of a west-flowing creek approximately 5 kilometres south of the confluence of the Red and Kechika rivers.

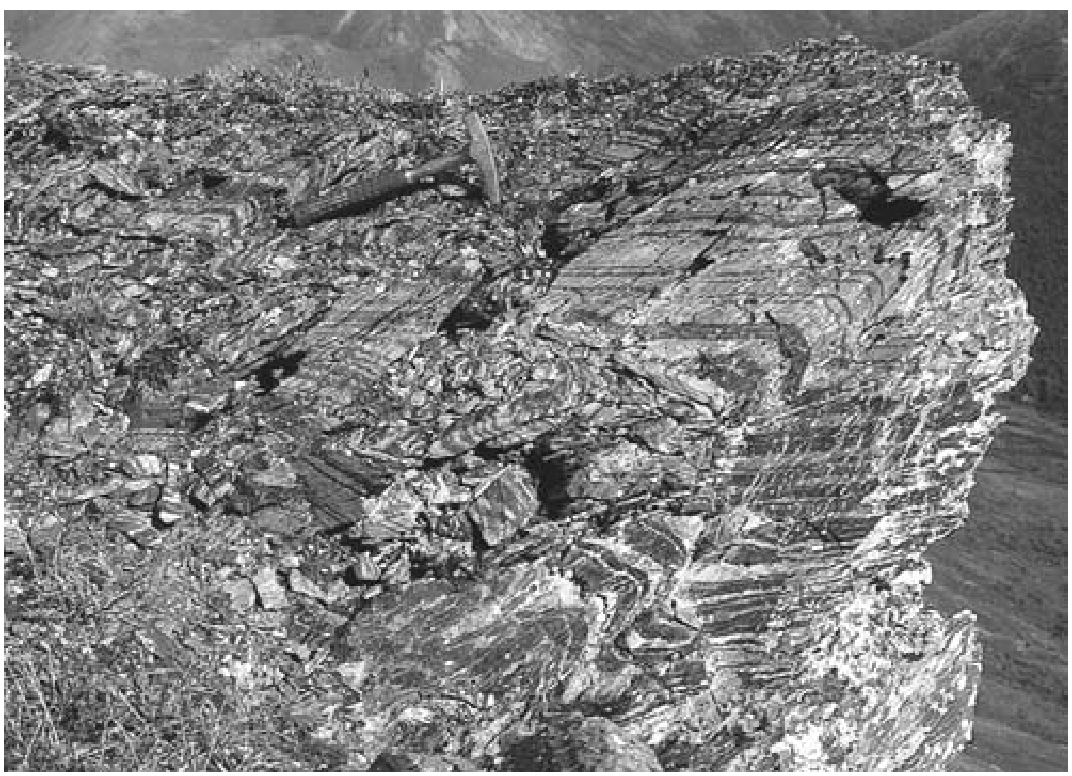

Photo 60. Similar-type folds developed in highly incompetent argillaceous lithologies of the Kechika Group. Note the well developed axial planar cleavage. The view is to the northwest and the outcrop is within the large area of Kechika Group rocks in the core of a northeasterly verging structure, east of Gataga Mountain.

zons such as unit Єc. These include the Brownie Mountain and Gataga Mountain anticlines (Photos 52 and 53). The Brownie Mountain anticline, as outlined by unit Єc, has a width of some 4 kilometres and a relatively short 10-kilometre length. Its northeast limb is overturned and cut by an easterly directed thrust carrying rocks of units Єcg and Єq. This thrust loses displacement northward and disappears in the core of the anticline. It plunges northwestward below an unusually broad belt of Kechika slates and limestones, which must represent the same anticline at this stratigraphic level. Structural cross-sections suggest that formation of this large fold cannot simply account for this anomalous thickness of Kechika strata (section D -D'). A blind thrust which repeats the Kechika Group and terminates within the core of this large anticline is a possible explanation. The northward continuation of this broad belt of Kechika rocks suggests this structure continues as far as Matulka Creek (section E - E').

The Gataga Mountain anticline begins several kilometres south of Gataga Mountain and ends at Terminus Mountain, some 20 kilometres to the northwest. This fold is similar in size and configuration to the adjacent Brownie Mountain anticline. It is delineated by Cambrian and Precambrian clastics, carbonates and volcanics. This large, northeast-verging fold is open to closed and its eastern limb is overturned (Photo 52). Superficially, this structure appears to be related to the underlying Gataga thrust fault, but the fault abruptly cuts off the fold, which suggests otherwise. The central part of the fold is cut by a smaller thrust(?) fault south of Matulka Creek and is clearly visible disrupting maroon beds of unit Єcgm along the top of the ridge.

Folds generally become more open and upright north of Terminus Mountain (sections F - F' and G - G'). Recognition of thrust faults in this region is hampered by the monotonous nature of the lithologies. Thus the broad region of open folding within the Road River Group north of Terminus Mountain may actually be more complicated than depicted, with both thrusts faults and folds giving a structural style like that of the broad region of Kechika rocks between the Gataga and Kechika rivers (section A - A').

Early Folding?

Locally, calcareous and noncalcareous rocks of the Aeroplane Lake panel exhibit layer-parallel to sub-layer-parallel tight to isoclinal folds (Photos 61 and 14). They are best developed in calcareous rocks along the east side of unit PPal and are also associated with higher grade metamorphism. Many of these folds have rootless limbs

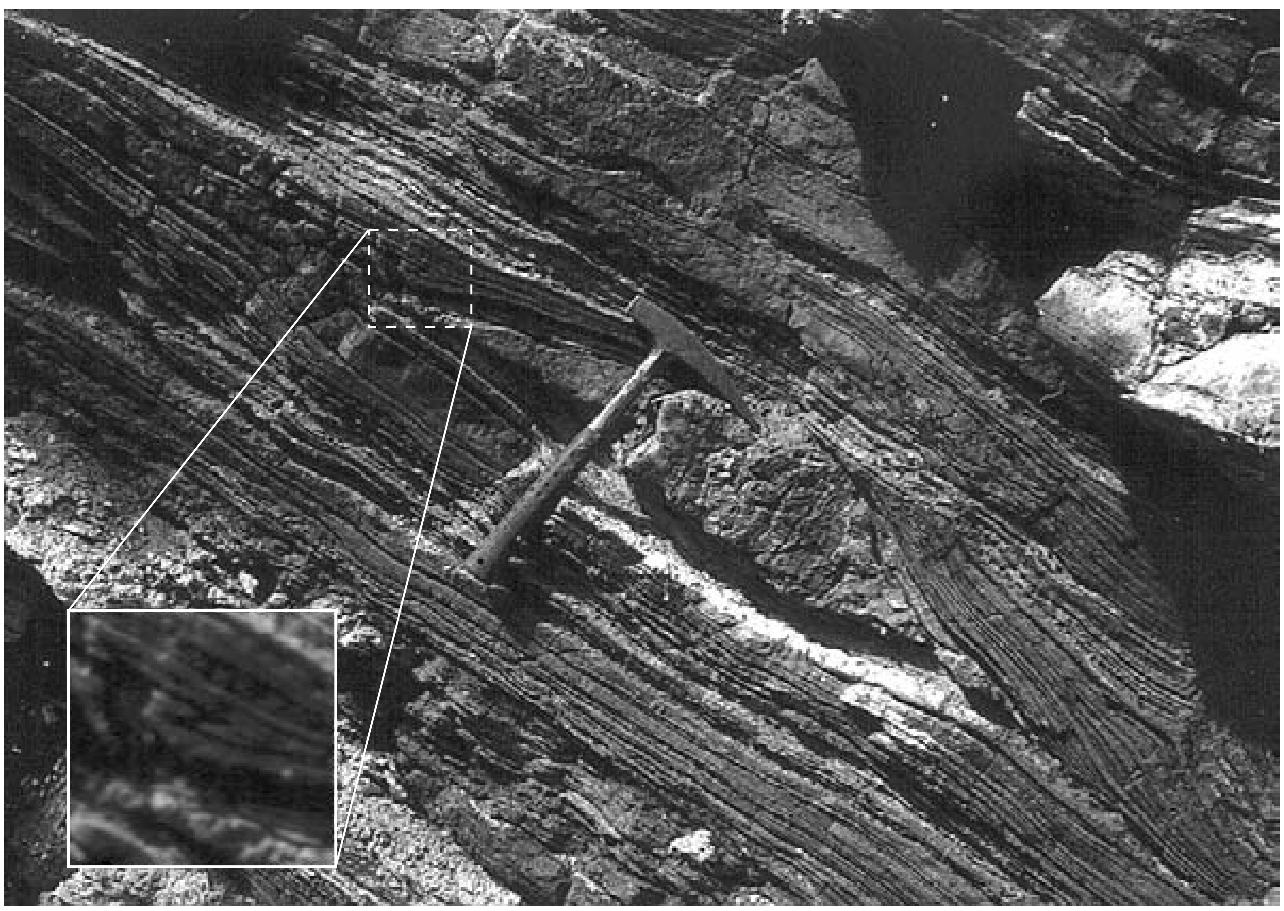

Photo 61. Layer-parallel fabric in calcareous lithologies of unit PPal (Aeroplane Lake panel) seen 'wrapping around' a more competent lens of carbonate. Small isoclinal folds (inset) are associated with this fabric. This early deformation is cut by latter upright fold structures (*see* Photo 14). This outcrop is on the east side of the ridge approximately 10 kilometres northeast of Twin Island Lake.

and the host lithology may exhibit a strong layer-parallel ductile fabric, as seen in unit PPal, suggesting intense shearing. Folds and the layer-parallel fabric were affected by the dominant upright folding which crenulates the earlier fabric.

The significance of this folding is not fully understood. It suggests the presence of an earlier phase of deformation linked to a pulse of increased metamorphism, but textural relationships suggest that peak metamorphism occurred during crenulation folding. The higher metamorphic grade still suggests this region was subjected to higher overall temperatures than other parts of the map area, which resulted in increased ductility. These early structures may simply have formed during the initial phases of a protracted period of thrusting within the Rocky Mountain fold and thrust belt. It is known that shortening within this structural province occurred over a period spanning the Cretaceous to earliest Tertiary. It can be demonstrated, from the character of the clastic wedge shed eastward from the tectonically thickened crust, that deformation occurred in pulses. Thus, layer-parallel folding within the Aeroplane Lake panel may have resulted from early and intense movement along a significant fault, or series of faults, resulting in transposition of bedding and cleavage in these zones. Outside these localized strain zones, resulting structures were more upright and had orientations typical of the Rocky Mountain fold and thrust belt. Subsequent shortening would have refolded this layer-parallel fabric, whereas away from these zones, upright structures would be amplified.

CLEAVAGE

A pervasive, slaty cleavage is present within argillaceous rocks throughout the map area (Photo 62). Cleavage is rare in clean quartzite and carbonate, but when present it is a widely spaced fracture cleavage. Thinly to moderately interlayered quartzite and slate commonly display classic refractive cleavage-bedding relationships. A pressure-solution cleavage is sometimes seen in argillaceous limestones. Analysis reveals that cleavage generally displayed a northwest-striking and southwest-dipping attitude. Northeast-dipping cleavage is observed in areas where associated fold structures are southwest verging; such as in the Split Top Mountain and Aeroplane Lake areas.

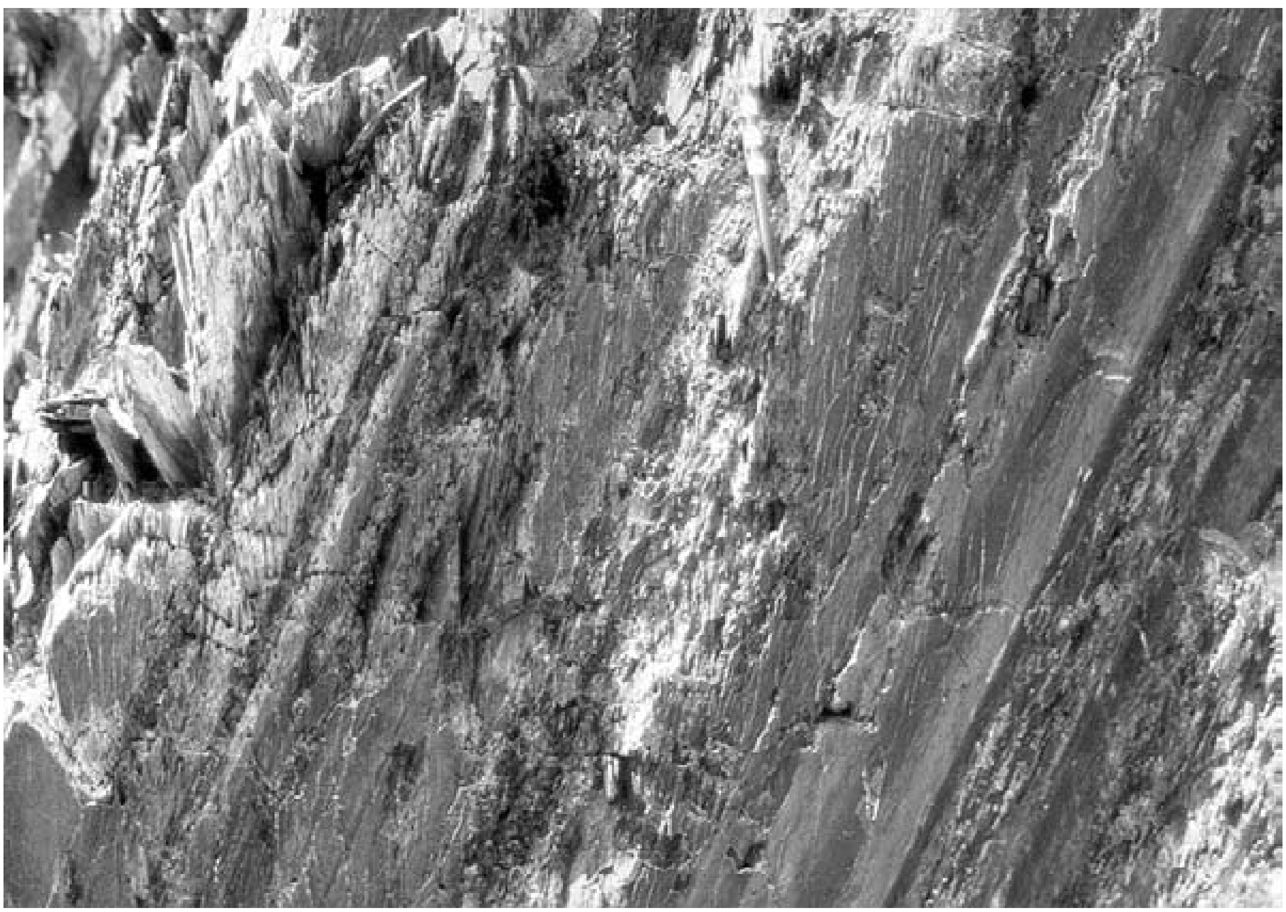

Photo 62. Well developed slaty cleavage in orange-weathering dolomitic slates of the Kechika Group, about 3 kilometres northwest of Bluff Creek. Due to the argillaceous nature of most lithologies, cleavage is the dominant structure at the outcrop level. It may be either penetrative, as seen here, or a more spaced cleavage in more competent sandstones, or a dissolution cleavage in carbonate-rich rocks. Some lithologies, such as clean carbonate of unit Cc or quartzite of unit Cq lack cleavage.

A crenulation cleavage is present within higher grade schists and phyllites of the Aeroplane Lake panel. It generally strikes north-northwest to north-northeast, and dips gently to steeply east (Figure 17). Crenulated phyllites and schists are associated with polydeformed carbonate rocks

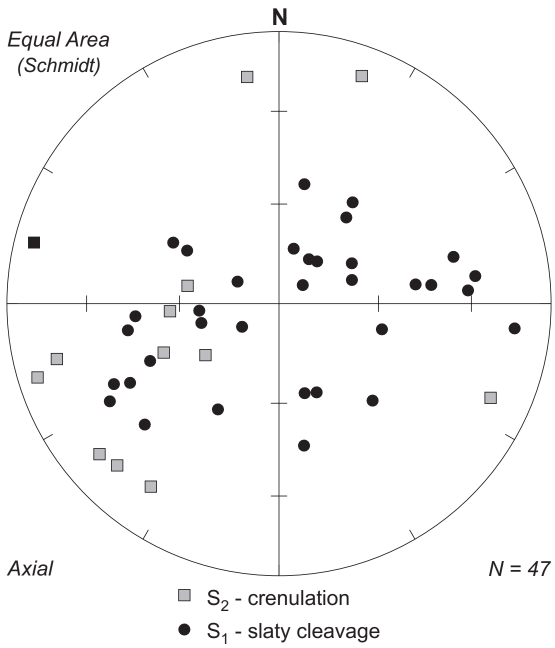

Figure 17. Poles to slaty (S_1) and crenulation cleavage (S_2) plotted on an equal area (Schmidt) stereonet. Data points are from the strata of the Aeroplane Lake panel.

(*see* section on Folding). Lithologies in parts of the Aeroplane Lake panel contain a strong, layer-parallel fabric with associated tight folds and these are overprinted by broader, upright fold structures with axial planes parallel to the crenulations.