Thrust slices and associated deformation in the Klondike goldfields, Yukon

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ABSTRACT

Regional-scale thrust faults in the Klondike District separate major lithologic units that include medium-grade metamorphic rocks of the Upper Permian Klondike Schist and middle to late Paleozoic Finlayson (Nasina) assemblage, as well as relatively low-grade greenstone and ultramafic rocks of the Slide Mountain terrane. These units were emplaced in the Jurassic as a series of kilometre-scale stacked thrust slices that are locally separated by additional ultramafic slices. A distinctive set of post-metamorphic compressional structures related to thrusting, particularly a set of ductile recumbent folds and associated spaced cleavage, is preserved in all thrust slices and is well developed near bounding faults. In carbonaceous units within the Klondike Schist, spatially associated with some thrusts, carbonaceous material is locally concentrated along the thrust-related spaced cleavage. Thrust-related fabrics are overprinted by kink-folding that locally affects the Finlayson assemblage, but is mainly developed in Klondike Schist. Gold-bearing veins appear confined to Klondike Schist and were emplaced in local sites of extension controlled principally by axial surfaces of these kink folds.

RÉSUMÉ

Dans le district du Klondike, des failles de chevauchement d'échelle régionale séparent d'importantes unités lithologiques, y compris des roches de métamorphisme moyen du Schiste de Klondike datant du Permien tardif, un assemblage de Finlayson du Paléozoïque tardif, ainsi que des roches ultramafiques et des roches vertes de métamorphisme relativement faible du terrane de Slide Mountain. Ces unités, mises en place pendant le Jurassique, consistent en une série de lambeaux de chevauchement empilés d'échelle kilométrique séparés par endroits par d'autres lambeaux ultramafiques. Un ensemble distinct de structures de compression post métamorphiques liées au chevauchement, plus particulièrement un ensemble de plis couchés ductiles avec un clivage espacé connexe, a été conservé dans tous les lambeaux de chevauchement et est bien formé près de failles limitrophes. Dans les unités carbonées du Schiste de Klondike, que l'on trouve associé à certains chevauchements, le carbone semble être concentrés par endroits le long du clivage espacé asoocié aux failles de chevauchements. Les fabriques de chevauchement sont soumises à la surimpression de plis en kink qui sont développé par endroits dans l'assemblage de Finlayson, mais qui se retrouvent surtout dans le Schiste de Klondike. Des filons aurifères vraisemblablement circonscrits au Schiste de Klondike ont été mis en place dans des zones de distension localisées principalement délimitées par les surfaces axiales des plis en kink.

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INTRODUCTION

The Klondike goldfields have produced at least 20 million ounces (600 million grams) of alluvial gold that was ultimately derived from orogenic (mesothermal) veins contained within the underlying Klondike Schist (Tyrell, 1907; Rushton *et al.*, 1993; Knight *et al.*, 1999; Lowey, 2005; Lebarge, 2007). The structural controls on the emplacement of these gold-bearing veins has been the focus of ongoing research (MacKenzie *et al.*, in press) and the relative timing of gold mineralization has now been placed in a framework of the main structural events that occurred during the evolution of the Klondike Schist (MacKenzie *et al.*, 2007, 2008 (this volume)). This study further contributes to our understanding of the structural context in which the gold-bearing Klondike Schist has evolved.

Much of the preserved structural fabric within the Klondike Schist and within the other major lithologic units in the Klondike District is directly linked to their emplacement as a series of stacked thrust slices. Individual thrust slices are bounded by major regional-scale faults that separate the main lithologic packages. The nature and characteristics of these faults and their preserved deformational structures have not been previously described in detail. The main reason is that exposure of the bounding faults is generally poor and identification of the faults within individual lithologic units, such as the Klondike Schist, is very difficult because of the lack of contrasting rock types across faults. This investigation examines several of the major bounding thrust faults that separate the main basement lithologic units in the Klondike District, as well as some of the thrust faults which occur within the Klondike Schist.

This paper outlines results of a detailed structural investigation of regional-scale faults in the northern and central Klondike District during the 2007 field season. Due to the generally poor exposure in the area, this study focuses on a few key exposures in lower Bonanza Creek in the northern Klondike District, and some recent exploration trenches and road cuts in the central Klondike District. This work has been carried out as part of a regional study of the entire Klondike District and adjacent Indian River area (J. Mortensen, D. MacKenzie and D. Craw, work in progress) that is being funded by Klondike Star Mineral Corporation.

REGIONAL GEOLOGY

The main basement lithologic units of the Klondike District form part of the Yukon-Tanana terrane and include medium-grade metamorphic rocks of the Upper Permian Klondike Schist, carbonaceous schist of the Devonian–Mississippian Finlayson assemblage (Nasina facies), and little-metamorphosed Late Paleozoic greenstone and ultramafic rocks of the Slide Mountain terrane (Fig 1.; Mortensen, 1990, 1996; Mortensen *et al.*, 2007). These units were thrust-imbricated in the Early Jurassic (Mortensen, 1996) resulting in a series of stacked thrust slices that are locally separated by lenses of ultramafic rocks. The uppermost slices are Klondike Schist and consist of complexly interleaved (1- to 100-m-scale) greenschist-facies quartzofeldspathic, chloritic, micaceous and minor carbonaceous schists. The two upper slices of Klondike Schist host significant orogenic gold and are the focus of current research into the structural controls on gold-bearing veins (MacKenzie *et al.*, in press).

The thrust stack was uplifted through the brittle-ductile transition in the Jurassic and unconformably overlain by locally derived sedimentary and volcanic rocks in the Late Cretaceous (Mortensen, 1996). Regional extension and normal faulting continued from Late Cretaceous to early Eocene with initiation of the strike-slip Tintina fault, along which rocks of the Klondike District were offset ~450 km from the rest of the Yukon-Tanana terrane (Gabrielse *et al.*, 2006). Minor regional uplift continued in the late Tertiary when erosion produced the Pliocene White Channel Gravels and the world-famous Klondike gold placer deposits (Lowey, 2005). Exposure of basement rocks in the Klondike District is generally poor due to extensive colluvium and permafrost on the tree-covered slopes (Bond and Sanborn, 2006).

THRUST FAULTS

Regional-scale thrust faults form the boundaries between the major lithologic units of the Klondike District (Figs. 1 and 2). The Klondike Schist occurs at the top of the thrust stack, in at least three different thrust slices separated by major thrust faults (Figs. 1 and 3). In lower Bonanza Creek, an additional thrust fault cuts the northern Klondike Schist slice at Cripple Hill (Fig. 3; see below), indicating that there may be other, still unrecognized, thrust slices within the unit. Two thrust slices of Finlayson assemblage (Nasina facies) rocks underlie the Klondike Schist and these Finlayson slices are separated by a thrust slice of greenstone and discontinuous lenses of serpentinite.

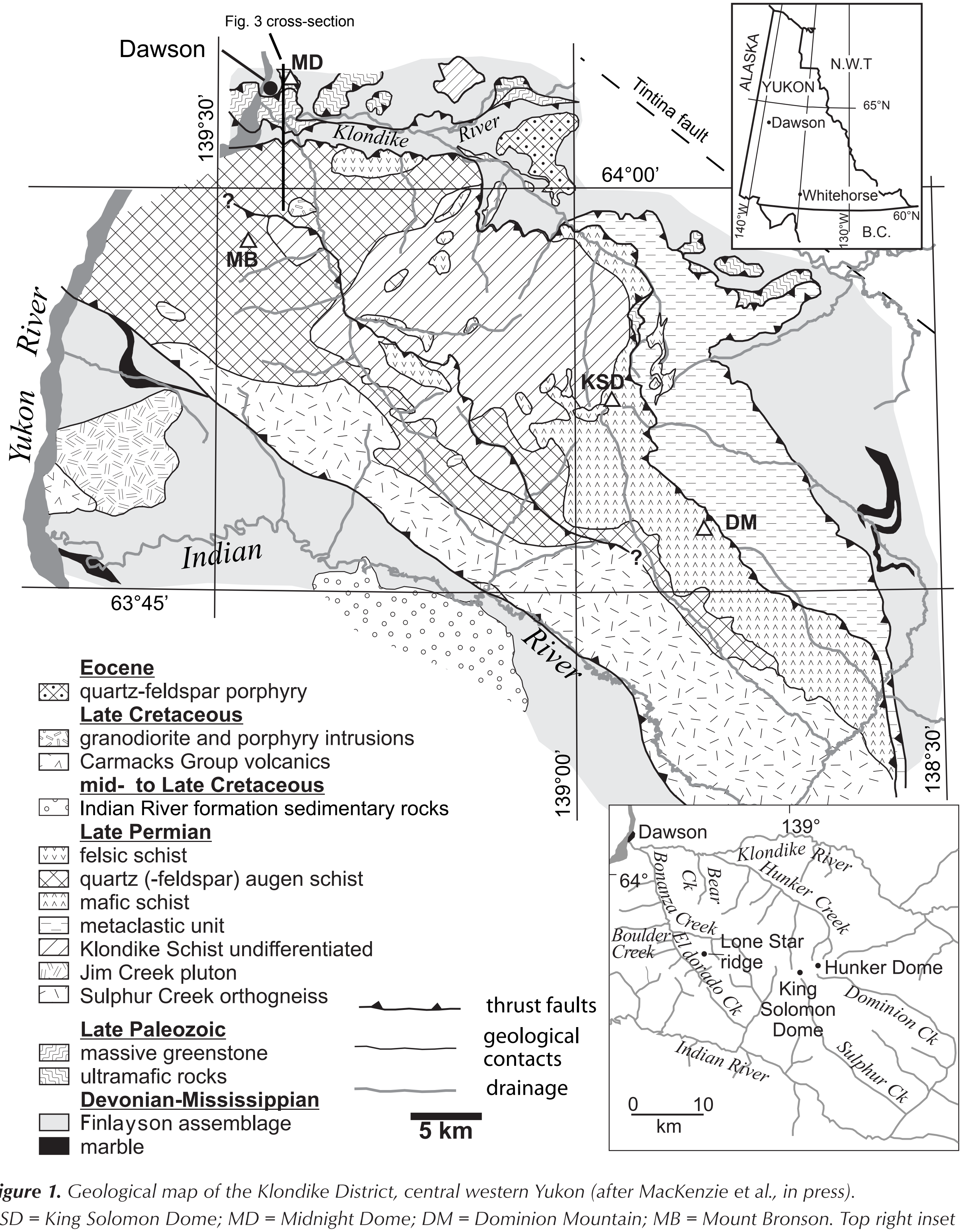

Figure 1. *Geological map of the Klondike District, central western Yukon (after MacKenzie et al., in press). KSD = King Solomon Dome; MD = Midnight Dome; DM = Dominion Mountain; MB = Mount Bronson. Top right inset map outlines the study area within Yukon, while bottom right inset map depicts the major drainages and physiographic features in the study area.*

At a regional scale, the faults bounding the slices are observed to be low-angle thrusts that separate the major lithologic units along widely spaced outcrops. At an outcrop scale, these faults are locally steepened and overprinted by later crosscutting structures. In a few places, the thrust faults are marked by lenses of sheared ultramafic rocks (Fig. 1) that typically pinch out along strike. Small isolated occurrences of sheared ultramafic rocks (serpentinite and/or talc schist) also occur locally within the Klondike Schist and are commonly associated with layers of strongly deformed carbonaceous schist (*e.g.,* Lone Star ridge, Fig. 1; Boulder Creek and Cripple Hill; Fig. 2).

All thrust slices are affected by a similar set of structures related to thrust emplacement. This set of structures comprises primarily post-metamorphic ductile folds and locally, a spatially associated late-stage phacoidal cleavage. In the Klondike Schist, these folds are designated F_3 (MacKenzie *et al*., 2007) because they demonstrably overprint and deform the pervasive metamorphic foliation and F_1 and F_2 folds transposed along it.

In this study, we use standard structural notation correlated for structures in the Klondike Schist, as these schists are the principal focus of our study. We project the same nomenclature and structural designator into the underlying structural slices for convenience, although we accept that this projection may turn out to be an oversimplification. For example, the metamorphic foliation in the Finlayson assemblage carbonaceous schists is similar to that of the Klondike Schist (designated S_2), but is defined by much finer grained micas (<100 μm) than in Klondike carbonaceous schists. Thus it may have formed under a relatively lower grade of metamorphism and not correspond to the second phase of deformation in the Finlayson assemblage. As a further example, the greenstone thrust slice and serpentinite lenses of the Slide Mountain terrane are locally foliated over several metres near the thrust, but are generally unfoliated further away. The foliation in these units is a thrust-related fabric that corresponds to F_3 and S_3 in Klondike Schist. The F_1 and F_2 events that produced the dominant ductile recrystallization fabrics within the Klondike Schist and Finlayson assemblage are interpreted to have formed in latest Permian time, considerably before the thrust faulting that imbricated the entire package. It is uncertain whether the Slide Mountain terrane experienced these two earlier deformation events. Hence, although the thrust-related ductile folds are designated F_3 in the Klondike Schist and all of the other slices, folds designated as 'F_3' in the Slide Mountain units may actually result from the first or second phase of deformation that affected the Slide Mountain terrane.

Post-metamorphic F_3 folds affect all the thrust slices and are best developed near thrust faults (within 100 m). The folds typically have rounded hinges, and in schist, form crenulations in the metamorphic segregations. Where the folding is most intense, in the hinges of macroscopic folds

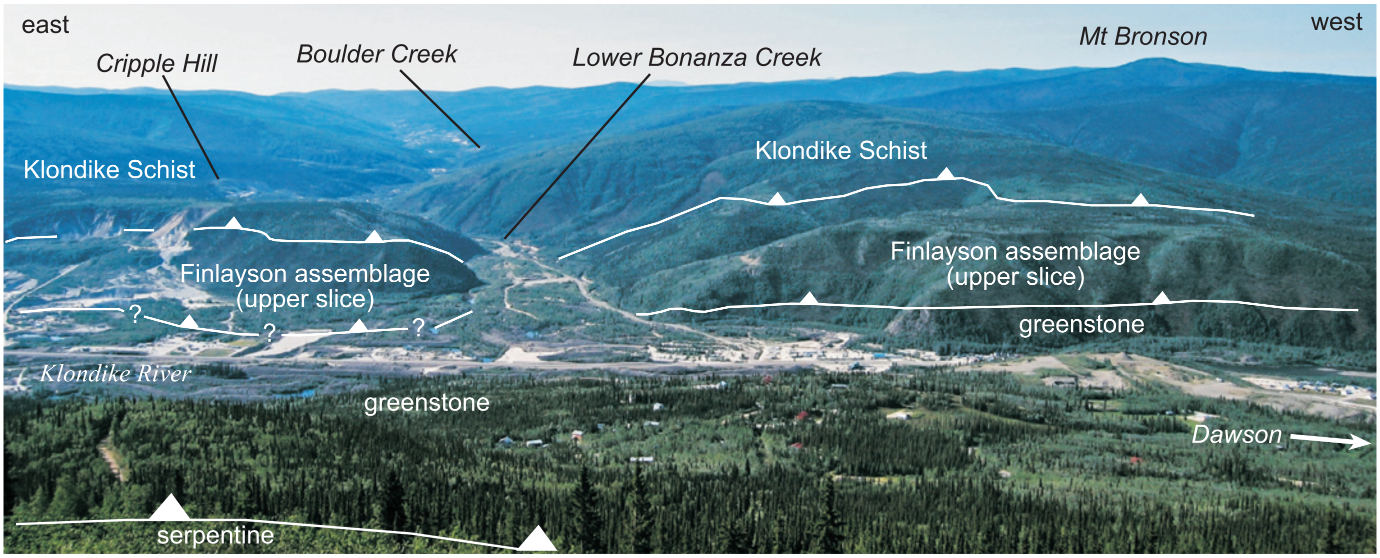

Figure 2. *Photograph of Bonanza Creek looking south from Midnight Dome (Fig. 1). The main thrust-fault contacts separating Klondike Schist, Finlayson assemblage, and greenstone and serpentinite of the Slide Mountain terrane are indicated by white lines with ticks on the upthrown side.*

and in foliated zones next to thrust faults, F_3 folds are associated with a variably developed spaced cleavage (S_3) parallel to fold axial surfaces. In the Klondike Schist, Finlayson assemblage, and greenstone thrust slices, S_3 and F_3 axial surfaces are generally shallowly dipping and lie subparallel to the main lithological contacts and thrust faults (Fig. 3g-k). Some of the more steeply dipping S_3 surfaces (Fig. 3j) are the result of local steepening next to later brittle faults and overprinting deformation. In the Finlayson and greenstone slice (Fig. 1), and in the Klondike Schist north of Boulder Creek (Fig. 2), F_3 fold axes plunge gently northeast-southwest (Fig. 3 c-f). To the south of Boulder Creek, the F_3 fold axes plunge in a different orientation, generally northwest-southeast (Fig. 3b). This may represent a rotation of the uppermost (southern) Klondike Schist thrust slices relative to underlying slices.

F_3 folds in Klondike Schist and Finlayson assemblage thrust slices are locally crosscut by a set of angular kink folds (F_4 in the Klondike Schist) with steeply dipping fold axial surface fractures. These kink folds affect all the thrust slices except the greenstone slice and serpentinite lenses, and are only rarely observed in the Finlayson assemblage slices. The kink folding is most intensely developed in the Klondike Schist where kink fold axial surface fractures control the emplacement of gold-bearing mesothermal veins (MacKenzie *et al.*, 2007, in press).

F_4 structures and gold-bearing quartz veins are crosscut by normal faults and associated zones of gouge that are correlated with Late Cretaceous regional extension (Mortensen, 1996). Many of these normal faults were localized by zones of pre-existing structural weakness, and metre-wide zones of steeply dipping normal fault gouge commonly overprint thrust exposures. Similarly,

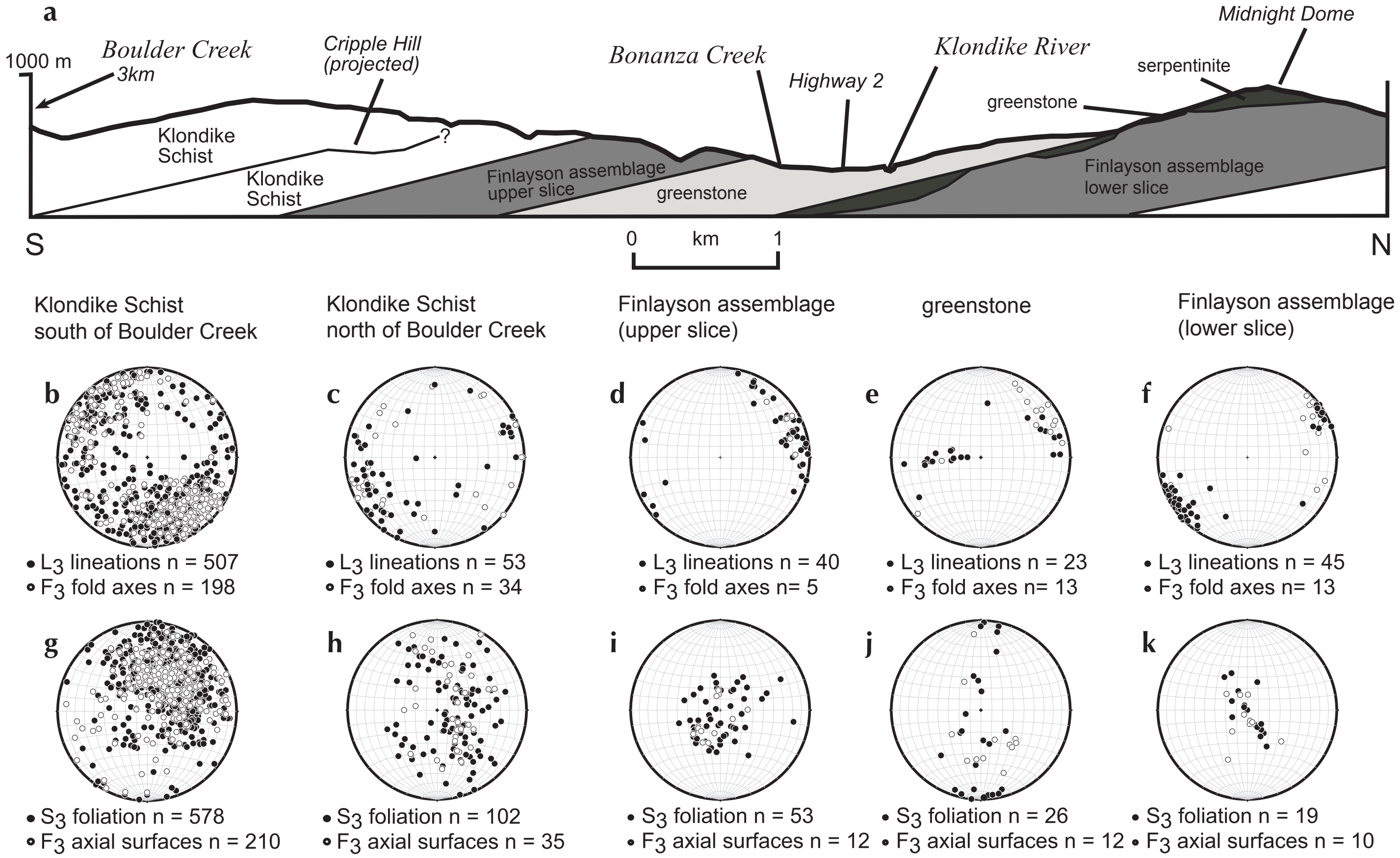

Figure 3. (a) *North-south cross-section through the northern Klondike District as located in Fig. 1.* ***(b-k)*** *Lower hemisphere equal-area stereonets for regional structural data depicting F_3 fold axes and L_3 crenulation lineations and poles to S_3 foliation and F_3 axial surfaces;* ***(b)*** *and* ***(g)*** *Klondike Schist south of Boulder Creek;* ***(c)*** *and* ***(h)*** *Klondike Schist north of Boulder Creek;* ***(d)*** *and* ***(i)*** *upper slice of Finlayson assemblage;* ***(e)*** *and* ***(j)*** *greenstone-ultramafic thrust slice;* ***(f)*** *and* ***(k)*** *lower slice of Finlayson assemblage.*

Late Cretaceous and Eocene dykes (Mortensen, 1996) have intruded fault zones and commonly obscure the thrusts on an outcrop scale. Hence, clear exposures of the thrusts, without these later overprints, are rare.

GREENSTONE–UPPER FINLAYSON ASSEMBLAGE THRUST

The thrust fault that separates the greenstone slice from the overlying upper Finlayson thrust slice is well exposed in a line of bluffs on the northwest side of lower Bonanza Creek (Fig. 1). Here, a large outcrop of variably foliated greenstone underlies carbonaceous and minor interlayered felsic schists of the Finlayson assemblage (Fig. 4). Greenstone is characterized by a weak, generally shallowly dipping metamorphic layering (designated S_2, Fig. 4e) which becomes more steeply dipping near the top of the bluff and crenulated about northeast-plunging F_3 axes (Fig. 4f). The S_2 metamorphic foliation in Finlayson assemblage schists (Fig. 4b) is steeply north and south-dipping about northeast-plunging F_3 fold axes (Fig. 4c).

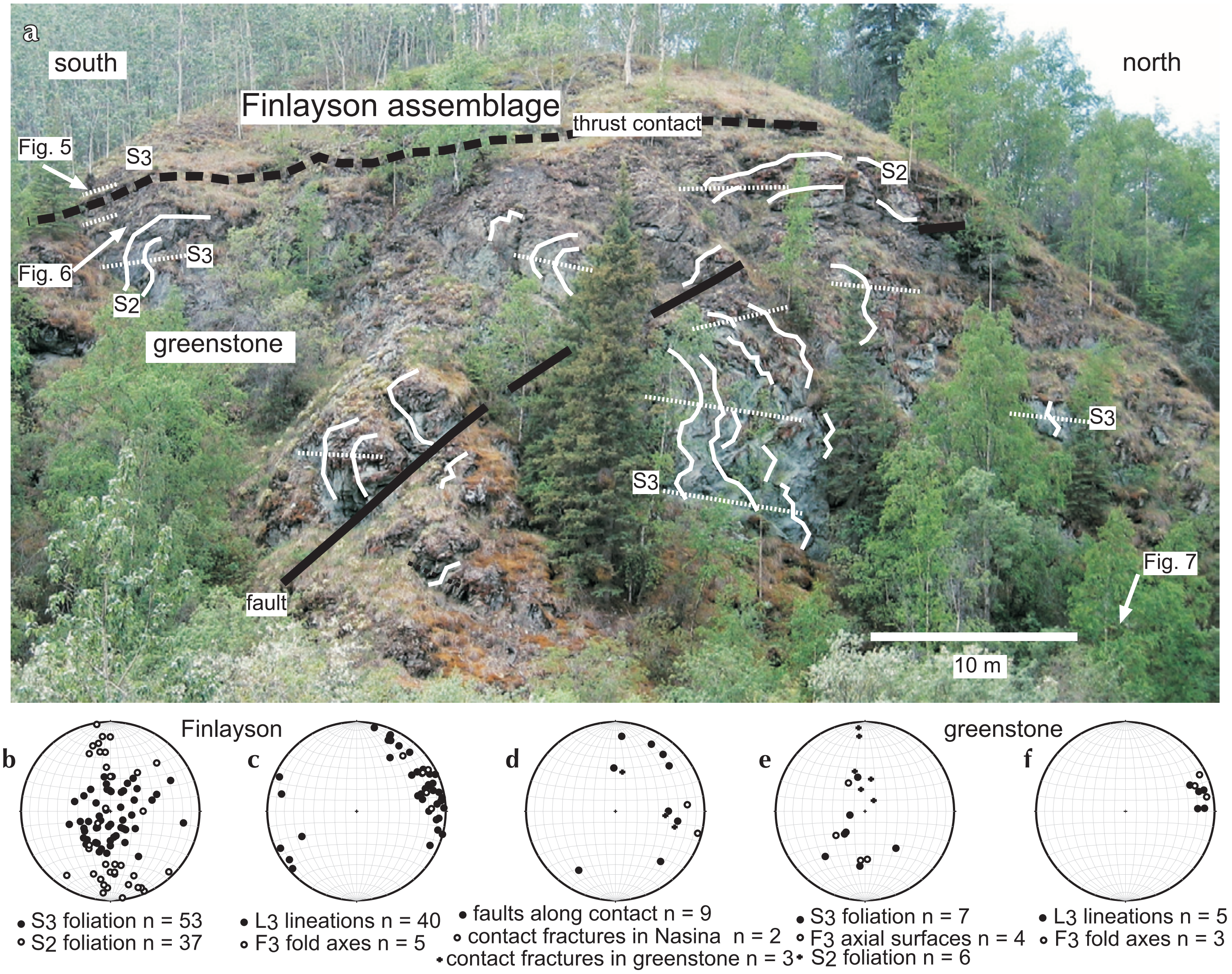

Figure 4. *Thrust contact between upper slice of Finlayson assemblage and greenstone-ultramafic slice, exposed in lower Bonanza Creek.* ***(a)*** *Steeply dipping S_2 foliation surfaces in greenstone (solid white lines) are crenulated about northeast-plunging fold axes (L_3). The S_3 spaced cleavage in greenstone (dashed white lines), is generally shallow, northeast-dipping (especially near the bottom), but is more gently dipping near the top of the bluff and dips to the southwest along the thrust (black dashed line). More steeply dipping faults and fractures locally cut the rocks along the contact. Lower hemisphere equal-area stereonets* ***(b-f)*** *of structural data from exposures on lower Bonanza Creek; (b), (d) and (e) are poles to planes.*

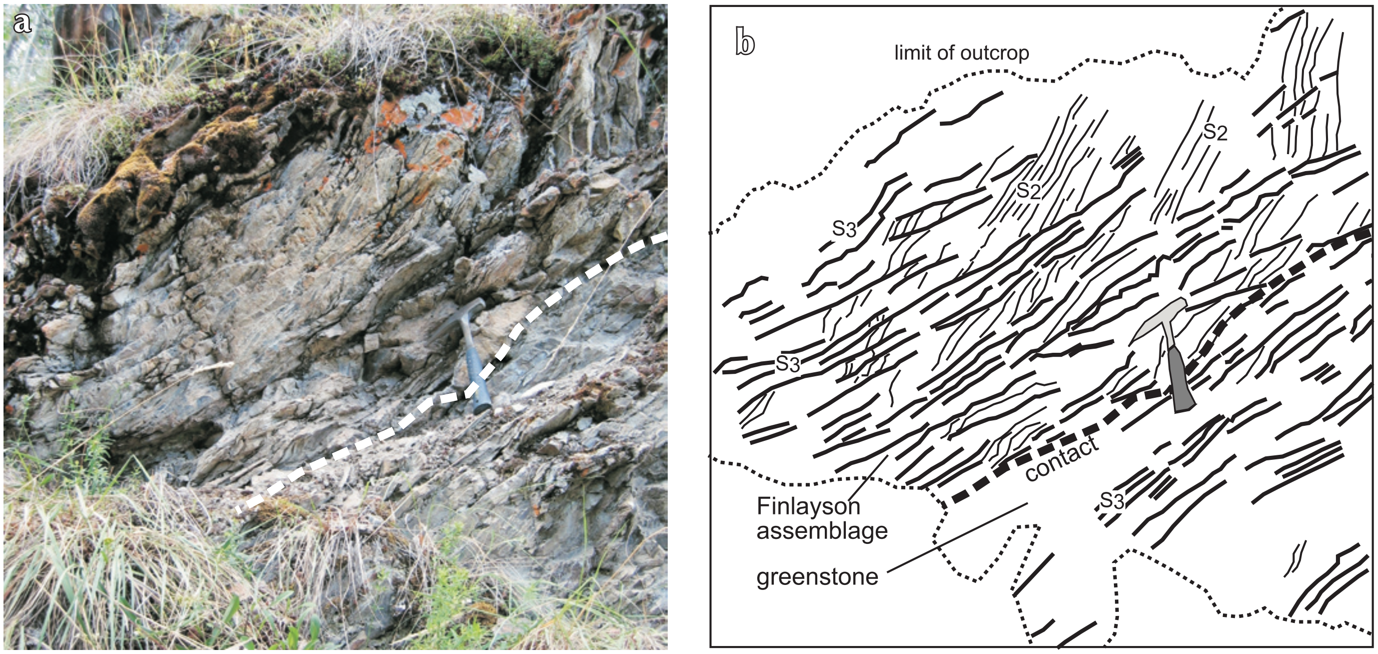

Figure 5. *Photograph* ***(a)*** *and sketch* ***(b)*** *of the thrust contact between the upper slice of Finlayson assemblage and greenstone near the top of the greenstone bluff (Fig. 4). A well developed S_3 spaced cleavage (thick black lines) crosscuts the steeper S_2 foliation (thin black lines) in the Finlayson assemblage, and in both units, S_3 is subparallel to the thrust contact (heavy dashed line).*

This metamorphic foliation has been tightly folded next to the thrust fault and is overprinted by a strong S_3 spaced cleavage (Figs. 4b, 5). The spaced cleavage crosscuts the metamorphic foliation and comprises a set of discrete millimetre-scale zones, oriented parallel to the axial surfaces of F_3 folds, in which metamorphic micas have been rotated into parallelism. Overall, the thrust fault separating the two lithological packages is gently southwest-dipping, and the S_3 spaced cleavage in Finlayson assemblage schist (Fig. 4b) and underlying greenstone (Fig. 4e) is subparallel to it. Locally, along the fault surface, higher angle faults and fractures (Fig. 4d) crosscut the fault plane and obscure the thrust fault's overall gentle dip.

Figure 6. *Outcrop of greenstone just below the thrust fault contact with the upper slice of Finlayson assemblage in Figure 4. The greenstone is well foliated and crenulated with a shallow-dipping spaced cleavage (dashed lines) with little or no recrystallization of micas. The spaced cleavage and folds are axial planar parallel to the contact in Figure 5.*

Greenstone next to the thrust fault is highly folded (Fig. 6), and thrust-related, fault-parallel spaced cleavage is well developed across several metres (Fig. 5). The spaced cleavage in the greenstone is defined by zones of deflection and rotation of metamorphic chlorite, and some recrystallized fine-grained (<100 µm) chlorite that is aligned along S_3 cleavage surfaces. Further from the fault contact, the spaced cleavage gives way to tight folds, and at the base of the cliff, the greenstone is massive with only subtle banding defined by alternating chlorite-rich and epidote-rich layers (Fig. 7).

UPPER FINLAYSON ASSEMBLAGE – KLONDIKE SCHIST THRUST

The upper contact of the slice of Finlayson assemblage with the Klondike Schist is poorly exposed and is best observed in lower Bear Creek (Fig. 1). Here, the contact between the two units consists of sheared schist dipping 50-60° to the southeast. On either side of the contact, the S_3 spaced cleavage is strongly developed and dips moderately to the south, subparallel to the contact. In other outcrops along the Klondike River valley, and near the inferred fault contact (Fig. 3i), S_3 spaced cleavage remains strongly developed, with a variable dip between outcrops (locally steep) that may reflect local overprinting of the thrust by steeper structures. In outcrop, the generally gently dipping metamorphic foliation is crosscut by a prominent, finely spaced (centimetre-scale) S_3 cleavage (Fig. 8). Large (10-m scale) recumbent F_3 folds in Finlayson assemblage schist occur in lower Bonanza Creek, close to outcropping Klondike Schist, but the thrust contact is not exposed. Soft gouge that is possibly related to a later normal fault, and highly folded and deformed carbonaceous Klondike Schist, crop out near the inferred thrust contact.

THRUSTS WITHIN KLONDIKE SCHIST

In the overlying Klondike Schist south of the upper slice of Finlayson assemblage, S_3 spaced cleavage and F_3 fold axial surfaces dip variably to the northwest and southeast (Fig. 3h). The L_3 crenulation lineations and F_3 fold axes plunge generally northeast-southwest (Fig. 3c). Thrust-related structures in this northern Klondike Schist thrust slice have the same general orientation as those in the underlying Finlayson assemblage and greenstone thrust slices (Figs. 3d-f and 3i-k).

F_3 folds and S_3 spaced cleavage increase in intensity near Cripple Hill (Figs. 2 and 3) where a thrust fault in Klondike Schist is locally exposed. The fault zone is delineated by

Figure 7. *Outcrop of greenstone near the base of the greenstone bluff in Figure 4. The greenstone is fairly massive with a subtle banding of light (epidote-rich) and dark (chlorite-rich) layers.*

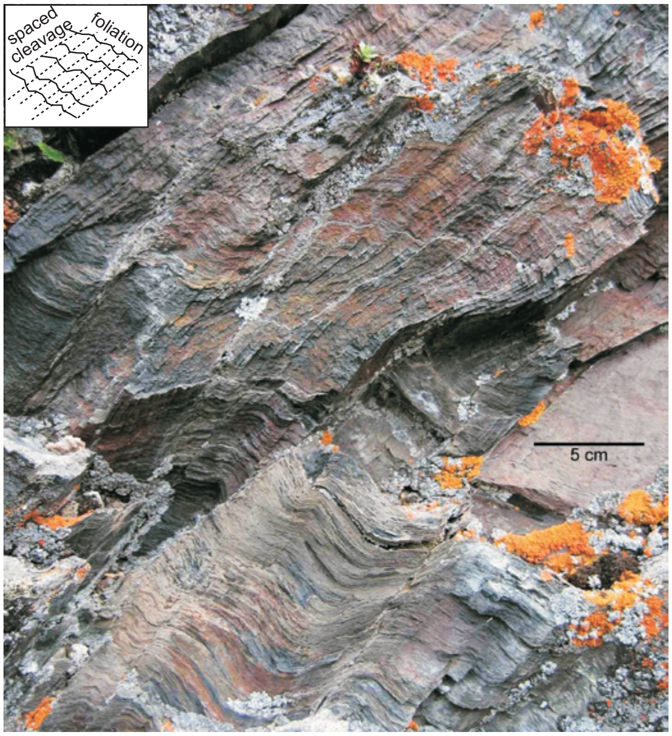

Figure 8. *Outcrop of the upper slice of Finlayson assemblage near (<100 m) the unexposed contact with Klondike Schist in lower Bonanza Creek. The fine wavy metamorphic laminations (left to right) are crosscut by a well developed S_3 spaced cleavage (bottom left to upper right).*

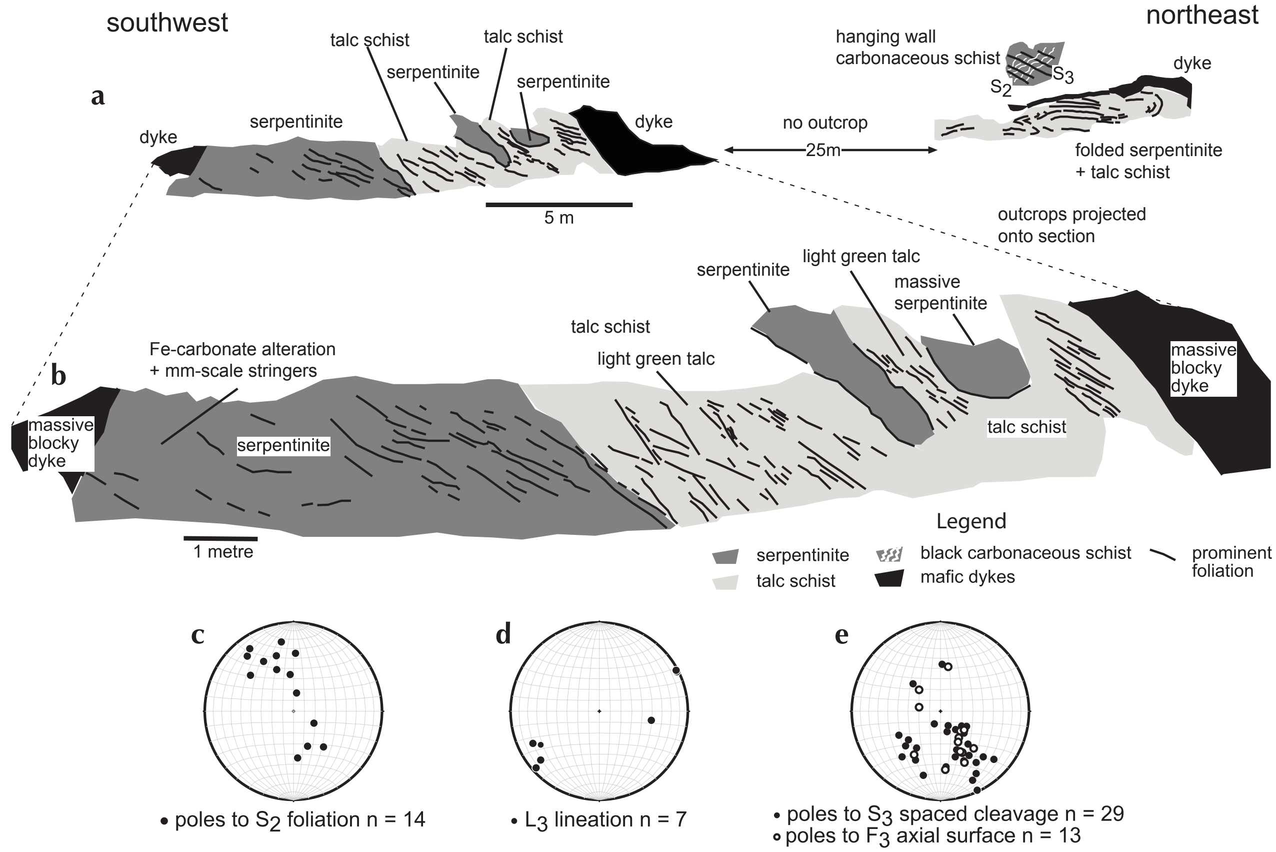

***Figure 9.** Sketch of road cut in placer workings at Cripple Hill **(a)** and detailed section **(b)** through the Cripple Hill thrust based on field sketches and photographs. Outcrops on the northeast end are projected onto section from an opposite face along an adjacent road cut. The zone is composed primarily of folded serpentine and talc schist intruded by several igneous dykes. Black carbonaceous schist in the hanging wall (locally interlayered with more quartzofeldspathic schist) delineates the relationship between S_2 metamorphic foliation (white lines) and S_3 spaced cleavage (black lines). Lower hemisphere equal-area stereonets for the area depict **(c)** poles to S_2 foliation in host schist, **(d)** L_3 crenulation lineations and **(e)** poles to F_3 axial surfaces and S_3 spaced cleavage.*

sheared lenses of talc schist and serpentinite (Fig. 9). Discontinuous horizons of black carbonaceous schist and interlayered quartzofeldspathic schist show strong S_3 cleavage next to the fault. These carbonaceous layers are unlike the Nasina facies carbonaceous schist of the Finlayson assemblage to the north. Carbonaceous units in Klondike Schist (see below) are distinguishable from those in the Finlayson assemblage by their coarser micas (>100 µm) and typically thicker (millimetre- to centimetre-scale) quartz segregations. The S_3 spaced cleavage is generally more strongly developed in Klondike Schist than in Finlayson assemblage schist, and is characterized by new growth of post-metamorphic muscovite and chlorite along S_3 cleavage surfaces. At Cripple Hill, the S_2 metamorphic foliation (Fig. 9a) is overprinted by a generally north-dipping S_3 spaced cleavage that parallels the thrust fault in this area (Fig. 9e). Structurally above the

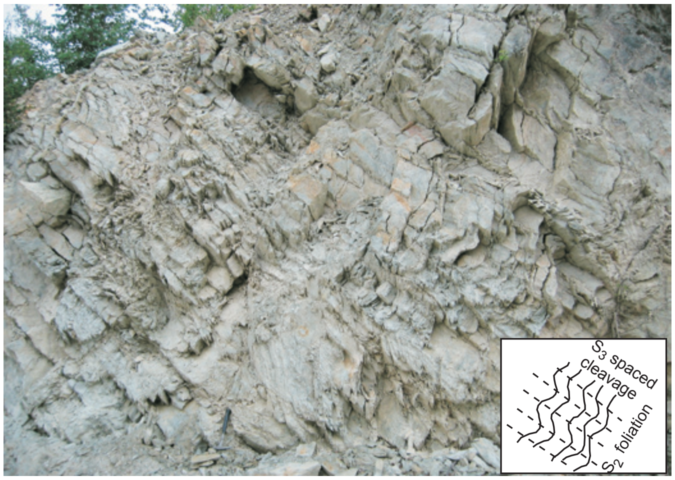

***Figure 10.** Quartz augen schist in the hanging wall of the Cripple Hill thrust. Simplified sketch illustrates the interpreted relationship between S_2 foliation (solid lines) and S_3 spaced cleavage (dashed lines).*

carbonaceous schist, outcrops of quartz augen schist (Fig. 10) have strong S_3 spaced cleavage up to several hundred metres from the thrust fault zone. The fault zone dips variably north, as defined by northward-dipping shears in serpentinite and talc schist. The contacts are obscured by the intrusion of several small intrusive bodies.

South of Cripple Hill, several other zones of intense F_3 folding and strongly developed S_3 spaced cleavage occur within the Klondike Schist (*e.g.,* Boulder Creek and Lone Star ridge; Fig. 1). The deformation zone at Boulder Creek is marked by highly folded carbonaceous schist and rare boulders of serpentinite partially altered by iron-bearing carbonate. Exposure here is poor, and apart from the strong F_3 folding and the presence of ultramafic boulders, evidence for any fault structure is lacking. To the south of this zone however, F_3 fold axes and L_3 crenulation lineations in Klondike Schist have a markedly different orientation than those in Klondike Schist and the upper slice of Finlayson assemblage to the north (Fig. 11). South of Boulder Creek, F_3 fold axes and L_3 lineations plunge predominantly northwest-southeast (Fig. 11a); north of Boulder Creek F_3 fold axes and L_3 lineations plunge northeast-southwest (Fig. 11b,c).

Within the southern Klondike Schist slice, another major thrust is exposed at Lone Star ridge (Fig. 1), where lenses of sheared serpentinite and talc schist outcrop in several exploration trenches (Fig. 12). At one exposure, the southwest-dipping hanging wall contact of the fault (Fig. 12c) is well preserved and displays a zone of strongly foliated talc separating highly crenulated carbonaceous schist and serpentinite. The serpentinite consists locally of massive pods, but is generally highly sheared with a phacoidal cleavage parallel to the contact. The footwall serpentinite-schist contact (Fig. 12b) is overprinted by several metres of steeply dipping fault gouge. At a different exposure of the same fault zone (>100 m to the southeast), the footwall contact between serpentinite and carbonaceous schist dips approximately 20° to the southwest, and the hanging wall contact dips gently northwest. Hence the dip of the thrust fault is somewhat irregular and variable along strike.

F_3 DEFORMATION IN CARBONACEOUS SCHIST

Carbonaceous schist is the dominant lithology of the Finlayson assemblage, and a similar lithology also occurs within the Klondike Schist where it is distinctly coarser grained and more coarsely segregated. Carbonaceous schist in the Klondike Schist is commonly spatially associated with thrust faults (Figs. 9 and 12) but also occurs in many other localities interlayered with felsic schist (Fig. 13). In Klondike Schist, individual bands of carbonaceous schist can be up to 10 m thick, but layers are typically only a few metres thick. Carbonaceous units are typically highly folded, with a well developed S_3 spaced cleavage especially near thrusts, and appear to be discontinuous and lens-like. The carbonaceous schist is typically highly fissile in all localities and appears to be much more strongly folded and have a more highly developed S_3 spaced cleavage than the surrounding more massive quartzofeldspathic schist.

In hand sample, carbonaceous schist consists of dark grey to black micaceous layers interlayered with millimetre- to centimetre-scale quartz and feldspar segregations (Fig. 14a-e). Carbonaceous schist typically contains up to 2-3% disseminated pyrite cubes which weather readily to limonite. In many samples (Fig. 14a, c, d, e) a prominent S_3 spaced cleavage is developed parallel to F_3 crenulation fold axial surfaces, and this has been accentuated by the relative concentration of black micaceous material along S_3 surfaces. The S_2 metamorphic foliation is typically truncated by seams of rotated metamorphic micas, newly

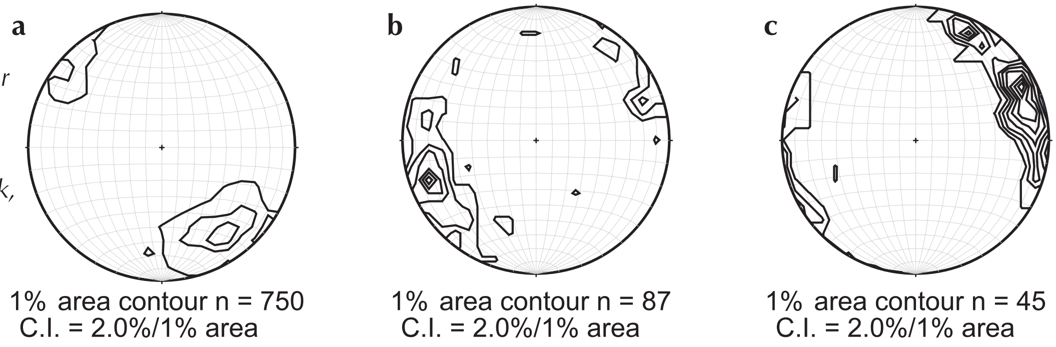

Figure 11. *Lower hemisphere equal-area stereonets of contoured L_3 crenulation lineations and F_3 fold axes for* ***(a)*** *Klondike Schist south of Boulder Creek,* ***(b)*** *Klondike Schist north of Boulder Creek, and* ***(c)*** *upper slice of Finlayson assemblage in lower Bonanza Creek. C.I. = contour interval.*

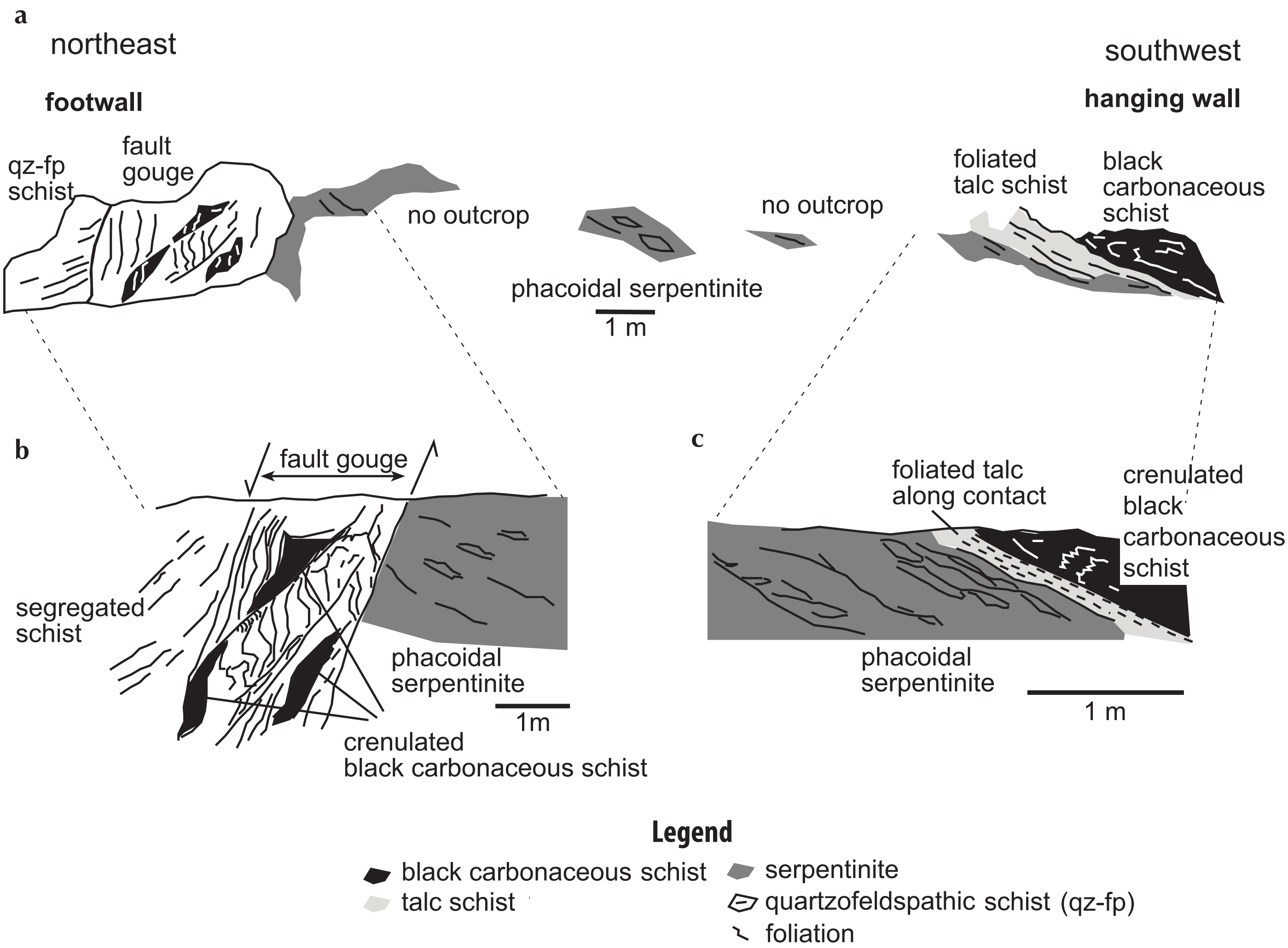

Figure 12. (a) *Composite section through the thrust at Lone Star ridge based on photographs and field sketches.* ***(b)*** *Detailed sketch of high-angle fault gouge that cuts across the contact between serpentinite and footwall schist.* ***(c)*** *Detailed sketch of the hanging wall contact between serpentinite and black carbonaceous schist.*

Figure 13. *Annotated photograph of interbedded black carbonaceous schist and brown quartzofeldspathic schist in O'Neill Gulch, a tributary of upper Bonanza Creek, on Lone Star ridge.*

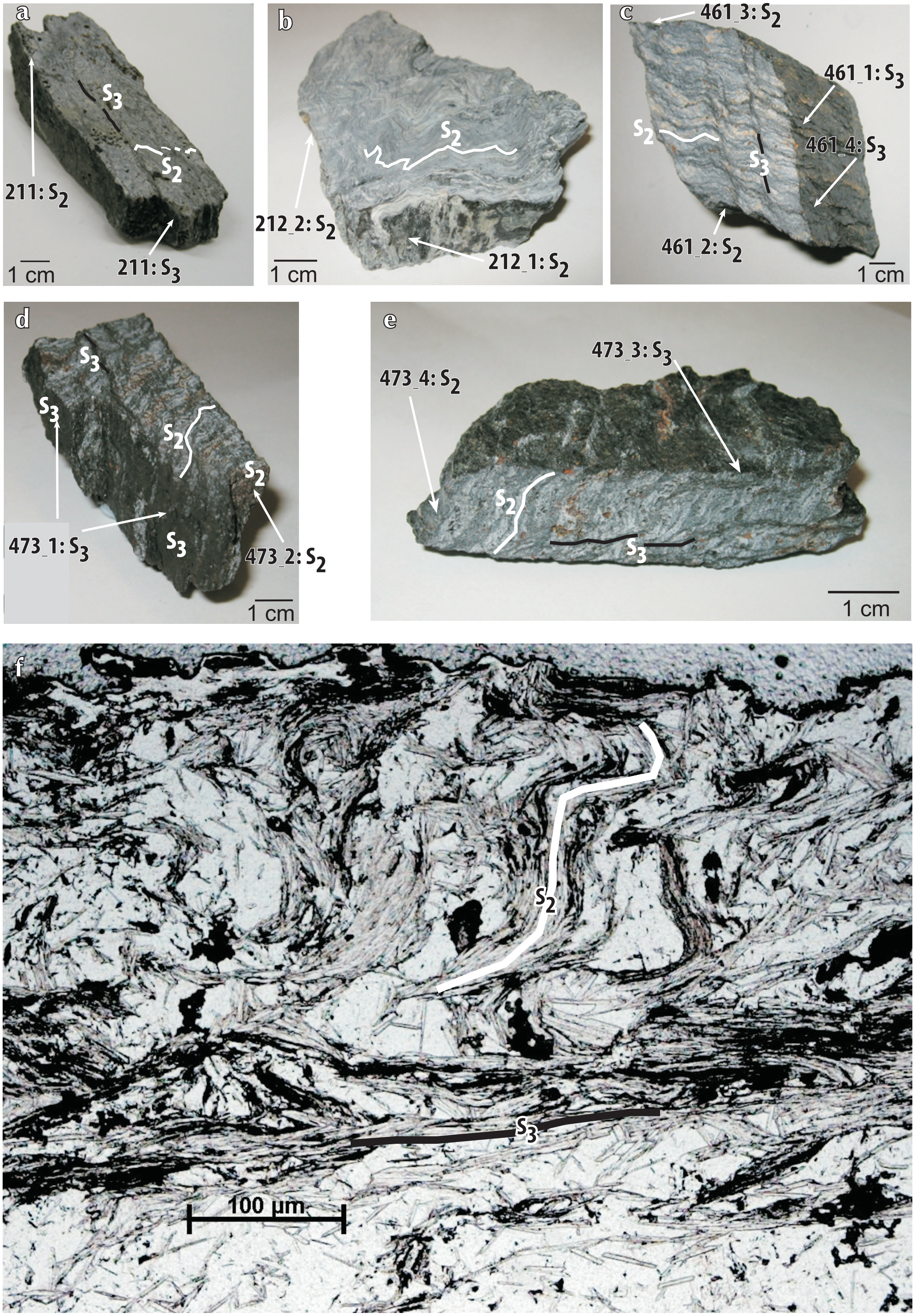

Figure 14. *Caption on next page.*

crystallized muscovite, and black carbonaceous material concentrated along S_3 cleavage surfaces (Fig. 14f).

Some of the black micaceous material on S_3 surfaces in the carbonaceous schist was analysed for carbon and compared with the micaceous layers on S_2 foliation surfaces. Samples of this material weighing ~300-500 mg were flaked off by knife. Approximately 3 mg portions were powdered and treated with hot (80°C) HCl (10%) for 8 to 12 hours to dissolve carbonates, then washed and dried. The treated powders were then analysed for carbon in a Carlo Erber CHNS Elemental Analyser, which has a detection limit of 0.1 wt%. The carbon analyses (Fig. 15) are a measure of the amount of non-carbonate carbon contained in the sample, but this method cannot distinguish between organic and non-organic origins for that carbon.

Figure 14. *(previous page) Samples of black carbonaceous schist **(a-e)** analysed for total non-carbonate carbon. Sample locations and the foliation surface that was sampled are indicated by the sample numbers. Samples 211, 212 and 473 are from different localities on Lone Star ridge and sample 461 is from Klondike Schist close to the Finlayson assemblage contact near lower Bonanza Creek. Sample numbers correspond to the values plotted in Figure 15. The orientation of S_2 metamorphic foliation is indicated by white lines and S_3 spaced cleavage by black lines. **(f)** Photomicrograph of sample in (a) illustrating black carbonaceous material and opaques (black) concentrated along S_3 surfaces (black lines).*

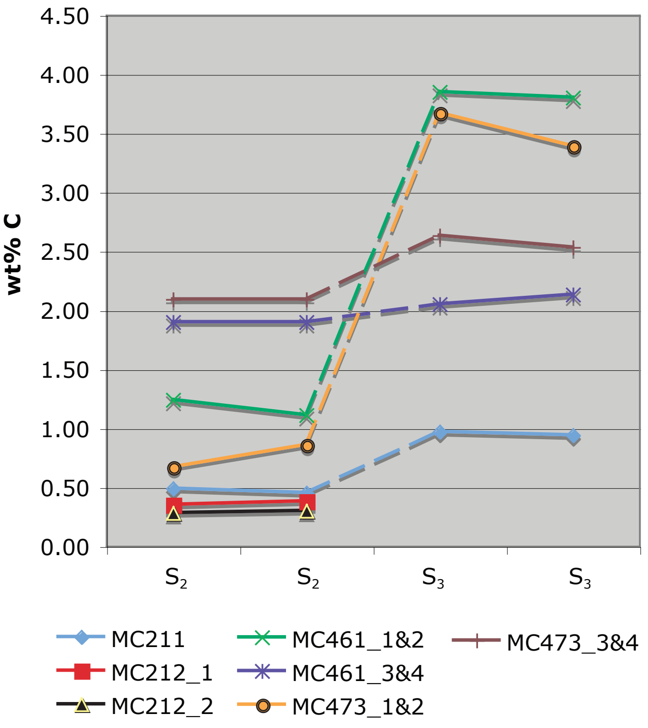

Figure 15. *Plot of non-carbonate carbon for carbonaceous schist samples in Figure 14. In each of the specimens, the S_2 metamorphic foliation and S_3 spaced cleavage surface was sampled, except for specimen 212 which had two different S_2 surfaces sampled. Each of the samples was then analysed twice.*

The results illustrate that for each of the samples, except 212, the total non-carbonate carbon was generally significantly higher in S_3 spaced cleavage surfaces than in the corresponding S_2 foliation surfaces of the same samples. Hence, development of F_3 has been accompanied by recrystallization and relative enrichment of graphitic material in the S_3 spaced cleavage. Localized graphitic enrichment may have resulted from centimetre-scale remobilization of graphite from S_2 foliation or loss of silica by pressure solution. This localized graphite enrichment may have facilitated the more intense deformation that characterizes these carbonaceous schists. Despite being highly crenulated, sample 212 did not contain any S_3 surfaces and its total non-carbonate carbon was very low (<0.5 %).

DISCUSSION AND CONCLUSIONS

The main lithological units in the Klondike district form a pile of stacked thrust sheets that were emplaced in the Jurassic in the latter stages of metamorphism as the rocks were uplifted through the brittle-ductile transition. Post-metamorphic ductile F_3 folds and an associated S_3 spaced cleavage affect all the major thrust sheets and are related to displacement on regional-scale thrust faults that form the boundaries between fault slices. In a few places (*e.g.*, lower Bonanza Creek, Fig. 4; and Lone Star ridge, Fig. 12c), the thrust faults are well exposed and dip gently southwest. These dips can vary along strike (*e.g.*, Lone Star ridge) and in some exposures, thrust faults dip locally northwest (*e.g.*, Cripple Hill). Exposure over most of the region is generally poor, however, and thrust faults are commonly overprinted by normal faults and dykes (Figs. 9 and 12b). On an outcrop scale, thrusts are locally crosscut by high-angle faults and fractures that locally disrupt and steepen the fault surfaces.

Thrust faults are typically marked by F_3 folds and well developed S_3 cleavage. Zones of intense F_3 folding and strongly developed S_3 cleavage are observed in several other outcrops in Klondike Schist away from the main thrusts mapped in Fig. 1 (*e.g.,* the headwaters of Bear Creek, inset Fig. 1). The differences between the schist on either side of these zones are not evident, so these zones may not necessarily indicate relative displacement by thrust faulting. Nevertheless, these zones represent significant localized semi-ductile deformation subparallel to the foliation. Where strong F_3 folding is associated with sheared ultramafics, major displacement along faults is suggested. The presence of sheared serpentinite and talc schist at Cripple Hill for example, indicates that the Klondike Schist is more imbricated than previously thought. Likewise, the differing orientations of L_3 to the north and south of Boulder Creek (Fig. 11) support relative movement between these schist slices.

Although a relatively minor constituent, carbonaceous schist is widely distributed throughout the Klondike Schist. It is distinguished from Nasina facies carbonaceous units in the Finlayson assemblage by its generally wider millimetre-scale quartz segregations and coarser mica grain size of >100 µm. Many of the mapped thrust faults and F_3 deformed zones in Klondike Schist are associated with discontinuous lenses of carbonaceous schist (Figs. 9 and 12). Non-carbonate carbon in these units is concentrated along S_3 cleavage surfaces and may act to focus strain along these surfaces in a process of deformation weakening.

Thrust-related structures are locally overprinted by a set of F_4 kink folds with a more brittle style than F_3 folds. The kink folds occur locally in the Finlayson assemblage, but are most prominent in Klondike Schist. Kink fold axial surface fractures crosscut the metamorphic foliation at high angles and are locally filled by quartz. Quartz veins in Finlayson assemblage sampled at lower Bonanza Creek assayed below detection level (<5 ppb) for Au, but gold-bearing veins hosted in similar structures are widely dispersed in the Klondike Schist. The main stage of gold mineralization occurred during, or after F_4 kink folding and therefore after major regional compression and thrust stacking. Normal faults offset gold-bearing veins and crosscut F_3 and F_4 structures. The main phase of gold mineralization was localized into post-metamorphic compressional structures in the Klondike Schist after the rocks were uplifted through the brittle-ductile transition and before extensional normal faulting.

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