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STRUCTURES ALONG FINLAY–INGENIKA FAULT, McCONNELL CREEK AREA, NORTH-CENTRAL BRITISH COLUMBIA

(94C/5; 94D/8, 9)

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INTRODUCTION

The study area is located in the vicinity of Johanson Lake, some 350 kilometres north-northwest of Prince George, bounded to the northeast by the north-northwest-trending Lay fault and to the southwest by Willow Creek. The north-northwest-trending Finlay-Ingenika fault, one of the very prominent dextral strike-slip fault systems of north-central British Columbia (Gabrielse, 1985), passes through the western half of the study area.

The main aims of the project are to examine the structures on both sides of the Finlay-Ingenika fault, to provide geological evidence for the dextral transcurrent displacement and to study local deformation associated with it. Geological mapping in parts of map sheets 94C/5 and 94D/8, 9 at a scale of 1:5000, was conducted in 1990 and 1991. Preliminary results from the fieldwork of 1990 were reported last year (Zhang and Hynes, 1991). This report provides considerably more data on the nature of the deformation, and extends the mapped region southeast towards Aiken Lake and to the Hogem Ranges west of the Finlay-Ingenika fault.

Throughout the region, exposure on prominent ridges is excellent. Although primary access is possible via the gravel road from either Mackenzie or Fort St. James to Johanson Lake and the Cheni mine, the nature of the terrain necessitates use of a helicopter for camp moves.

REGIONAL GEOLOGY

The map area lies within the Intermontane Belt, one of the five morphogeological belts of the Canadian Cordillera (Wheeler and McFeely, 1987), and straddles the Quesnellia and Stikinia tectonostratigraphic terranes (Monger, 1984). North and south of the study area, Stikinia rocks are separated from those of Quesnellia to the east by the Cache Creek Terrane, a subduction-related assemblage, and bounded to the east by the Slide Mountain Terrane, a deep-water oceanic assemblage. These terranes were amalgamated by latest Triassic to earliest Jurassic time, forming a composite terrane, "Terrane I", which accreted to the ancient margin of North America in Jurassic time (Monger, 1984). Dextral strike-slip faulting took place extensively along the eastern margin of Terrane I, and possibly part of the Omineca metamorphic belt, during the late Cretaceous (Gabrielse, 1985). The Finlay-Ingenika fault, which lies between the Quesnellia and Stikinia terranes in the study area, is one of the dextral strike-slip faults on which the transcurrent motion occurred.

Quesnellia and Stikinia terranes in the study area are characterized by volcanic, volcaniclastic and sedimentary rocks of the Upper Triassic Takla Group. West of the Finlay-Ingenika fault the Takla Group was subdivided into three formations during 1:250 000 mapping of the McConnell Creek map area (Lord, 1948; Church, 1974, 1975; Richards, 1976a, b; Monger, 1977; Monger and Church, 1977). The lower Dewar Formation is dominated by volcanic sandstone, siltstone and argillite, and is overlain by a middle Savage Mountain Formation consisting of submarine, massive volcanic breccia and pillow lava with minor volcanic siltstone at the top. The upper Moose Valley Formation is predominantly reddish marine and nonmarine volcaniclastic rocks (Monger, 1977; Monger and Church, 1977). East of the Finlay-Ingenika fault the Takla Group remains undivided (Monger, 1977). It consists mainly of greenish grey, dark and pale grey volcanic, volcaniclastic and sedimentary rocks. No conclusive stratigraphic correlations have been made between the Takla Group rocks on either side of the fault (Minehan, 1989a, b). The Takla Group rocks east of the fault are extensively intruded by multiphase, early Jurassic to Cretaceous dioritic rocks (Woodsworth, 1976).

STRATIGRAPHY OF THE TAKLA GROUP EAST OF FINLAY–INGENIKA FAULT

Takla Group rocks east of the Finlay-Ingenika fault are predominantly volcaniclastic. They include some porphyritic rocks that are possibly volcanic flows and feeders, and minor sedimentary rocks. Stratigraphic successions and rock assemblages vary greatly from one locality to another. The stratigraphy and petrology have therefore been described separately for three different regions of the study area: the northwest (the Wrede Range), southwest (west of the Dortatelle fault) and southeast (between the Dortatelle fault and Kliyul Creek) (Zhang and Hynes, 1991, Figure 1-12-2).

In the southeastern region, a stratigraphic succession about 1500 metres thick along the east-trending ridges west of Aiken Lake (Figure 1-12-1) is lithologically very similar to that observed on the ridges between the Dortatelle fault (Monger, 1977) and Kliyul Creek (Zhang and Hynes, 1991; Figure 1-12-1). A lowest Unit 1 is dominated by grey volcanic sandstone. Most of this unit is covered by vegeta-

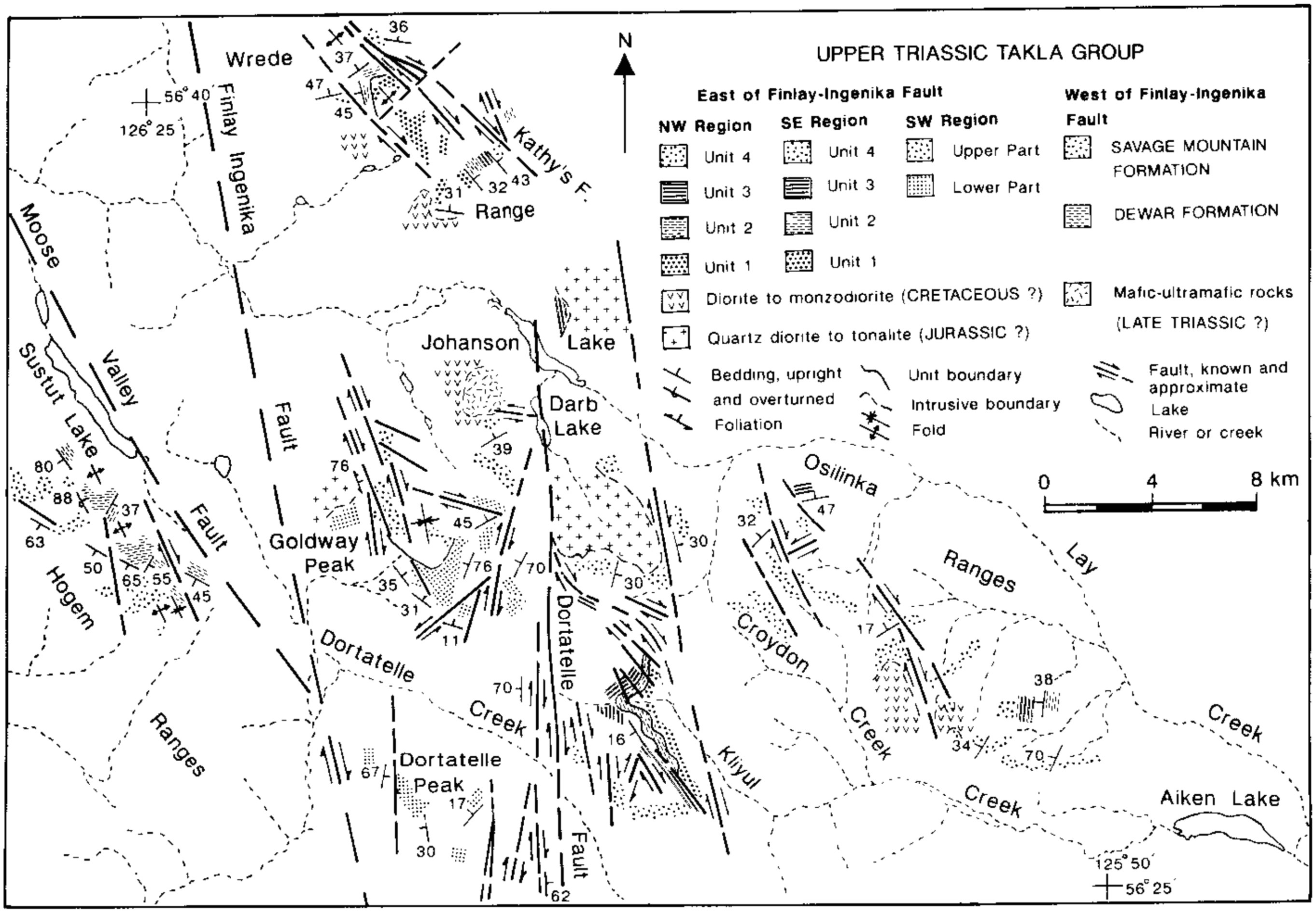

Figure 1-12-1. Generalized geology of the Johanson Lake area.

tion but a minimum thickness of 400 metres can be estimated west of Kliyul Creek. The top of this unit displays abundant recessive patches of carbonate. Unit 2 is up to 170 metres thick west of Kliyul Creek and attains a thickness of about 430 metres west of Aiken Lake. It consists of reddish weathering, black argillite with siltstone laminae and 2 to 10-centimetre layers or lenses of dark grey or black limestone. This unit also contains minor interbedded, grey volcanic sandstone and siltstone, ranging in thickness from 30 centimetres to several metres. Unit 3 is well exposed on the ridges west of both Kliyul Creek and Aiken Lake. The lower part is dominated by greenish grey volcanic siltstone which contains abundant fragments of dark grey or purplish, well-bedded limestone, ranging from several centimetres to several metres in diameter. Small-scale, slumping folds, generally several tens of centimetres in wavelength, are common in the fragments of the well-bedded limestone west of the Kliyul Creek, but not observed in those west of Aiken Lake. Fossils of brachiopods, bivalves and possibly some ammonites were found in the carbonate clasts west of Aiken Lake. The upper part is greenish grey or pale grey, medium-layered (10 to 20 cm) volcanic sandstone interbedded with dark grey or black, thin-layered limestone or black, dark grey to grey argillite (west of Aiken Lake). The thickness of this unit is up to 440 metres west of Kliyul Creek and 400 metres west of Aiken Lake. These limestone-rich beds are very widespread and useful marker horizons in the region. Unit 4 consists mainly of greenish grey, massive volcanic breccia and sandstone with minor clinopyroxene and clinopyroxene-plagioclase porphyries and is well exposed on the ridges east of the Dortatelle fault and northeast of Croydon Creek. The greenish grey breccias are compositionally heterogeneous and dominated by fragments of clinopyroxene and clinopyroxene-plagioclase porphyries. The fragments are angular to subrounded, commonly sitting in a porphyritic matrix with the same composition as the fragments, and average less than 20 centimetres in diameter. The breccias are usually poorly bedded and poorly sorted. The porphyritic rocks contain phenocrysts of either euhedral clinopyroxene or both euhedral clinopyroxene and anhedral plagioclase, commonly less than 5 millimetres in diameter but locally as much as 1 centimetre. The porphyritic rocks are generally several tens of centimetres to several metres thick and interbedded with the volcanic breccias, but sometimes occur as feeders where they cut the laminations of the volcaniclastic rocks, for example, on the ridges west of Aiken Lake. Rocks of this unit are very resistant and commonly cliff forming.

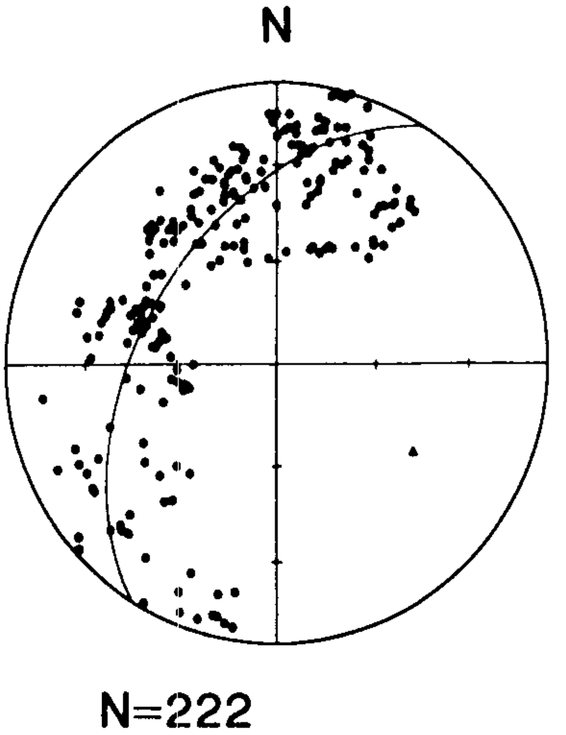

Figure 1-12-2. Stereonet plot of bedding planes from the Hogem Ranges. Solid circles: poles to bedding planes; open triangle: minimum eigenvector; great circle: plane normal to the eigenvector; N: number of measurements. Eigenvectors calculated using methods of Mardia (1972).

TAKLA GROUP WEST OF FINLAY-INGENIKA FAULT

Rocks of the Takla Group west of the Finlay-Ingenika fault are exposed in the Hogem Ranges (Figure 1-12-1) and are divided into two formations in the study area: Dewar and Savage Mountain (Richards, 1976a; Monger, 1977; Monger and Church, 1977).

The Dewar Formation is well exposed along the northern slopes of the Hogem Ranges. The lower part of the formation is dominated by reddish weathering, dark grey to black, locally graphitic and pyritic argillite with lenses of dark grey marly limestone. The upper part is mainly black argillite interbedded with pale grey volcanic sandstone and siltstone, with minor breccia containing fragments of argillite and volcanic sandstone. Beds ranging in thickness from laminae to 70 centimetres are common. The base of this formation is not exposed but a minimum thickness of 500 metres can be estimated.

The Savage Mountain Formation is characterized by massive, dark grey volcanic breccia with minor volcanic sandstone and siltstone. The fragments in the breccias are angular to subrounded and range in diameter from several centimetres to 40 centimetres. They consist of dark grey, reddish grey and dark purple clinopyroxene and clinopyroxene-plagioclase porphyries. The matrix of the breccias is predominantly clinopyroxene or clinopyroxene-plagioclase porphyritic. This unit contains locally conspicuous, coarse-grained, "bladed" feldspar porphyry. At the base of the formation one horizon contains clasts of purplish grey limestone and argillite with brachiopod and bivalve fossils. Rocks of this formation are very resistant and form high peaks in the area.

INTRUSIVE ROCKS

The Takla Group rocks east of the Finlay-Ingenika fault contain abundant intrusions associated with the Alaskan-type Johanson Lake mafic-ultramafic complex (Nixon and Hammack, 1990), and many dioritic to monzodioritic bodies occur north and south of Johanson Lake and north of Kliyul Creek. There are also many intermediate to felsic dikes and sills, typically less than 3 metres thick. These intermediate to felsic rocks are probably related to the Hogem batholith and early Jurassic to Cretaceous in age (Lord, 1948; Richards, 1976a; Woodsworth, 1976).

DEFORMATION

Rocks in the study area experienced deformation associated predominantly with dextral, transpressive displacement along the Finlay-Ingenika fault. Steeply dipping or vertical strike-slip faults (Figure 1-12-1) cut the rocks into a number of fault-bounded, weakly deformed blocks, in which cleavages and small-scale shear zones are the only visible structures. These characteristics are typical of continental crustal deformation associated with large-scale transcurrent faulting (*e.g.*, Nelson and Jones, 1986; Geissmar *et al.*, 1989; Ron *et al.*, 1986, 1990). In addition, there are some large-scale, open to medium folds with axes trending northwest to north-northwest (Figure 1-12-1).

FOLDS

Four large-scale folds have been recognized. The Wrede Range anticline and Goldway Peak syncline occur in the Wrede Range and Goldway Peak regions, respectively (Figure 1-12-1) and have been described previously (Zhang and Hynes, 1991). The Sustut Lake anticline and syncline are exposed in the Hogem Ranges area, immediately south of Sustut Lake (Figure 1-12-1).

The Sustut Lake syncline, which lies to the northeast of the anticline, involved only the black argillite and grey volcanic sandstone and siltstone of the Dewar Formation. Its northeastern limb is truncated by a north-northwest-trending, dextral strike-slip fault. The Sustut Lake anticline has the black argillite and grey volcanic sandstone and siltstone of the Dewar Formation in its core and dark grey volcanic breccia of the Savage Mountain Formation on both limbs. The southwestern limb dips steeply southwest and is locally vertical, or even overturned (Figure 1-12-1). Secondary, outcrop-scale folds are also developed. They are either symmetrical or asymmetrical in cross-section and very common in the well-bedded sedimentary rocks of the Dewar Formation (Plate 1-12-1d). Poles to bedding planes in the region fall on a great circle (Figure 1-12-2) and delineate a cylindrical fold axis trending at 122° with a plunge of 41°. The age of formation of the folds is unknown.

They were truncated by the faults and may therefore have developed during the early stages of the dextral transpression (*cf.* Wilcox *et al.*, 1973; Sylvester, 1988).

FAULTS

Subvertical or vertical strike-slip faults are the most widespread structural features in the study area. They are abundant along and near the Finlay-Ingenika fault, and become fewer and shorter away from it. On the ridges immediately west of Aiken Lake, for example (Figure 1-12-1), they are rarely seen. This spatial relationship of the strike-slip faults to the Finlay-Ingenika fault suggests that deformation in the study area was associated closely with the transcurrent motion on the Finlay-Ingenika fault and was largely restricted to a narrow belt, about 30 kilometres wide, adjacent to the major fault (Figure 1-12-1).

Based on the attitudes and slip senses, the faults were divided into four groups: dextral strike-slip faults trending northwest, north-northwest and north-northeast, and sinistral strike-slip faults trending east-northeast. All the faults can be readily interpreted as a resulting from dextral motion on the Finlay-Ingenika fault (Zhang and Hynes, 1991). The attitudes and slip senses of north-northeast and east-northeast-trending fault sets are consistent with their formation as Riedel (R) and conjugate Riedel (R′) shears, respectively, related to the main motion on the Finlay-Ingenika fault (*cf.* Tchalenko, 1970; Keller *et al.*, 1982; Sylvester, 1988). The northwest-trending faults generally display two stages of displacement. The earlier is dip-slip with a thrust sense, and the later is horizontal, dextral. The thrusts are thought to have developed in association with the initiation of dextral displacement on the Finlay-Ingenika fault (*cf.* Sylvester, 1988), with the dextral, strike-slip motion superimposed once the fault was fully established. Faults in the north-northwest-trending group are parallel to, and have the same slip senses as, the Finlay-Ingenika fault. They are inferred to have formed as secondary shears of the Finlay-Ingenika fault. At several localities, for example south of Darb Lake and north of Dortatelle Creek, dioritic dikes are incorporated in mylonitic zones associated with the faults, indicating that fault motions occurred after emplacement of the extensive dioritic plutons in the study area.

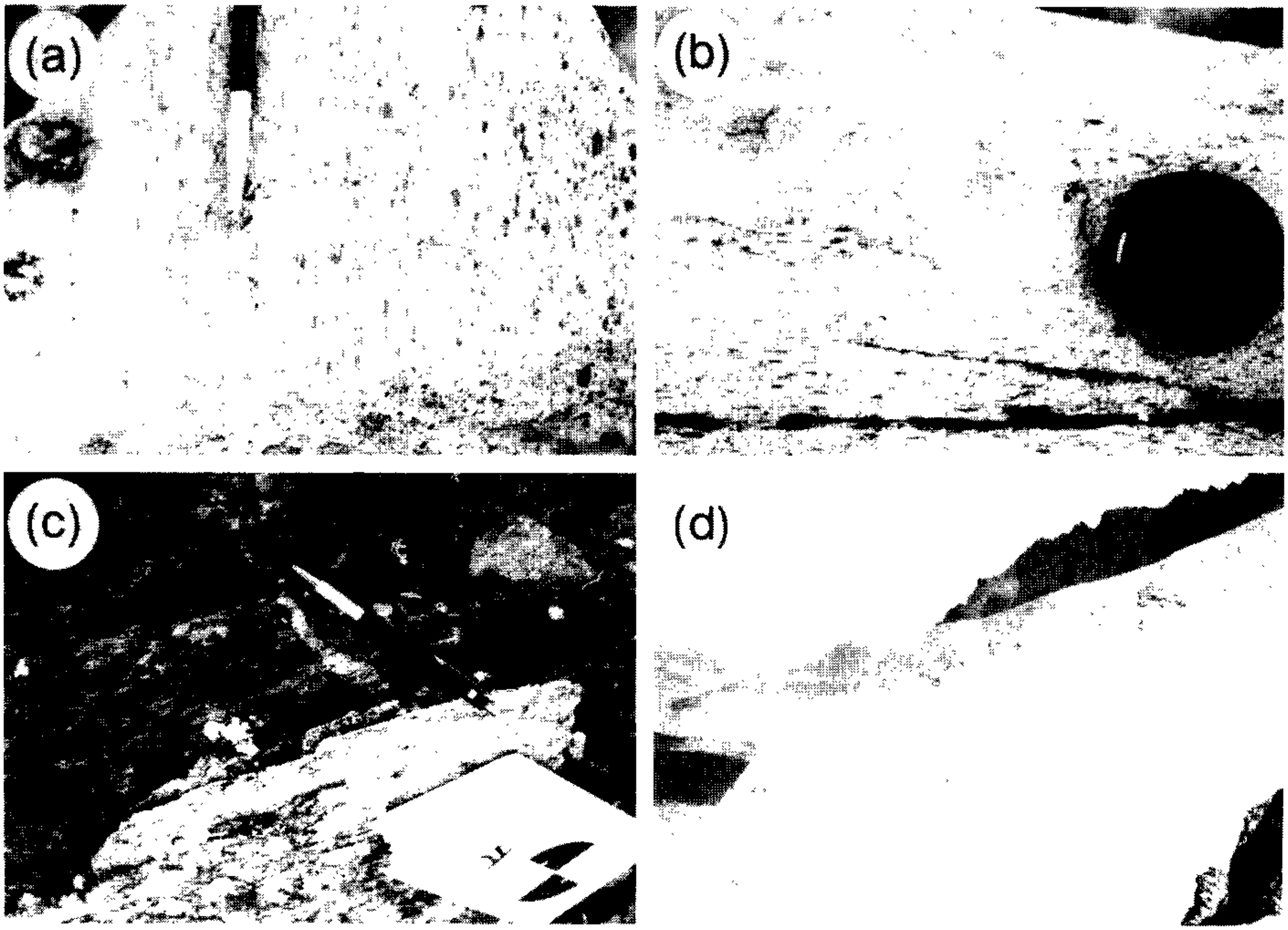

Plate 1-12-1(a). Primary mineral lineation in clinopyroxene porphyry; (b) Mineral stretching lineation in the north-northwest-trending faults east of Dortatelle Creek, looking northeast down. (c) North-northwest-trending fault west of Aiken Lake, pencil parallel to the extensional fissure filled with calcite fibres, book parallel to the fault plane, looking southwest down; (d) Outcrop-scale folds in well-bedded sedimentary rocks of the Dewar Formation in the Hogem Ranges, looking north.

The faults cut the Takla Group into fault-bounded, weakly deformed blocks, ranging in size from several square kilometres to tens of square kilometres (Figure 1-12-1). With progressive displacement on the Finlay-Ingenika fault, deformation was apparently concentrated in the previously formed fault zones, while the fault-bounded blocks remained only very weakly deformed. Cleavage is the only visible deformation outside the fault zones but within the fault zones rocks are strongly deformed and sheared into protomylonite to mylonite with a variety of kinematic indicators and fabrics, by which slip senses on the faults were determined.

KINEMATIC INDICATORS AND FABRICS

S-C mylonites (Berthé *et al.*, 1979; Lister and Snoke, 1984; Shimamoto, 1989) are present in most of the faults, especially as they pass through the greenish grey clinopyroxene or clinopyroxene-plagioclase porphyries or volcanic breccias. They provide one of the most useful kinematic indicators in the study area. The C surfaces are *predominantly closely spaced, displacement discontinuities* or zones of relatively high shear strain, while the S surfaces are characterized by alignment of phyllosilicate minerals such as chlorite (Zhang and Hynes, 1991, Plate 1-12-1c). Angles between the C and S surfaces vary from 40°± (in slightly deformed domains) to 0°± (in strongly deformed domains). Hundreds of the C and S surfaces were measured along the Dortatelle fault and the fault east of Goldway Peak, and intersections of them are always subvertical or vertical, suggesting that horizontal displacement was predominant in the study area.

Drag folds, developed in mylonitic foliation, are common features in the strike-slip fault zones, and also provide kinematic indicators. Such folds in the Dortatelle fault zone, for example, are tight and asymmetrical, ranging in wavelength from less than 1 centimetre to several tens of centimetres. Axial planes of the folds are subvertical, striking northwest, with fold axes trending northwest and plunging 70° to 80°, and have an angle of 35°± to the fault plane. This geometry is consistent with that of the S-C fabrics and indicative of dextral strike-slip.

Extensional fissures (Ramsay and Huber, 1983) are common along the strike-slip faults and even between some cleavage planes. They are commonly filled with fibrous tremolite or calcite that grew either perpendicular or subperpendicular to the walls, especially where they cut volcanic breccias or porphyries. Typical relationships are exhibited *in the north-northwest-trending fault on the ridge west of* Aiken Lake (Plate 1-12-1c). Here, slickenlines marked by fibrous crystals of calcite on the fault plane display a dextral strike-slip sense, and six extensional fissures filled with calcite fibres were measured along the fault. Figure 1-12-3 plots the structural data and local, tectonic principal strains (e_1, e_2, and e_3) which were determined based on the assumption that the motion on the fault is simple shear. It is obvious from the plot that the principal strain e_2, which is determined by the intersection of the fault plane and mean extensional fissure plane (Fisher, 1953), is approximately perpendicular to the slickenline (the angle between them on the fault plane is 88°). The slickenlines and extensional fissures are therefore in excellent agreement with dextral strike-slip on the fault. Furthermore, the Fisher's mean (Fisher, 1953) of poles to the fissures moved away from the maximum principal strain e_1 (Figure 1-12-3), indicative of clockwise rotation of the fissures as a result of progressive incremental straining after their formation.

In addition to the above principal kinematic indicators, *other fabrics such as stretching lineations and foliations* are well developed in the fault zones. There are two types of mineral lineation in the study area: primary and secondary. The primary mineral lineations occur only in the clinopyroxene or clinopyroxene-plagioclase porphyries, and were observed at two localities on the ridge between Dortatelle and Kliyul creeks. They are due to the alignment of prismatic crystals of clinopyroxene and hornblende(?) (Plate 1-12-1a). No evidence of deformation has been found although some mineral grains are partially or entirely replaced by chlorite or epidote, which may have obscured such evidence. In its absence, these lineations are tentatively attributed to primary processes. The secondary lineations are characterized by stretched mineral grains, now predominantly chlorite (Plate 1-12-1b) and are confined to fault zones, especially in the north-northwest-trending faults on the ridge between the Dortatelle and Kliyul creeks (Figure 1-12-1). The minerals are commonly stretched subhorizontally into ribbons up to several centimetres long, while on the vertical section they have subrounded shapes. The stretching lineations (Plate 1-12-1b) cut the contacts

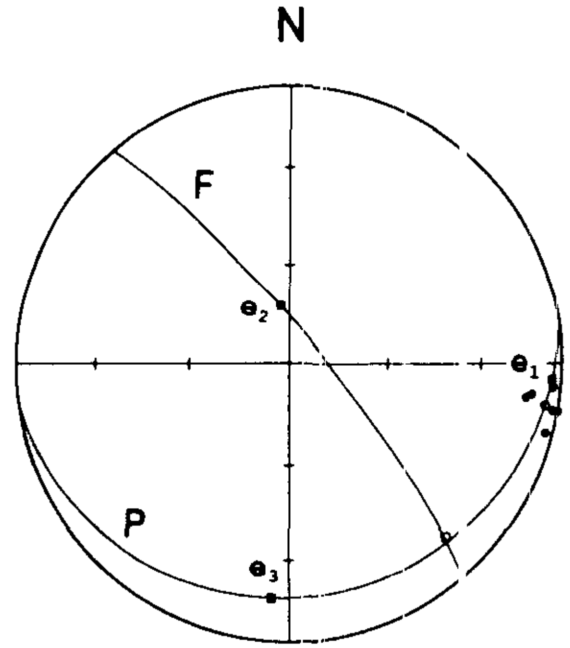

Figure 1-12-3. Stereonet plot of structural data from the north-northwest-trending fault on the ridge west of Aiken Lake. Solid circles: poles to the extensional fissure planes; solid square: principal strains (e_1, e_2 and e_3); open circle: Fisher's mean of poles to the extensional fissure planes; F: the fault plane; P: the principal plane normal to the intermediate principal strain (e_2).

between clinopyroxene-plagioclase porphyry and volcanic breccia, and minerals in different clasts of the breccia are aligned in the same direction, indicative of their deformational origin.

Foliations are the most common fabrics in or along the faults, and are characterized by parallel alignment of either phyllosilicate minerals or flattened fragments of volcanic breccia. Progressive development of cleavage due to flattening of volcanic breccia fragments is well developed in an area of about one square kilometre, bounded to the west by a north-northwest-trending, dextral strike-slip fault immediately north of the Goldway Peak. In the eastern part of this area fragments of clinopyroxene and clinopyroxene-plagioclase porphyries, in which phenocrysts of euhedral clinopyroxene and wispy plagioclase are relatively fresh, undeformed and randomly distributed, are only slightly flattened and may indeed have experienced deformation only during pyroclastic flow (Plate 1-12-2a). Passing westwards, a demonstrably tectonic flattening is superimposed, giving rise to a marked increase in the elongation ratio of fragments (Plate 1-12-2b), the local development of foliation, and deformation of a mafic dike (Plate 1-12-2d), which locally truncates the primary fabrics. In the western part of the area fragments are very strongly deformed, and foliations are extensive and penetrative in the breccia where the phenocrysts of euhedral clinopyroxene were no longer present (Plate 1-12-2c). The mean flattening plane strikes 335° and dips 73° northeast and makes an angle of 10° with the fault plane to the west, indicating that a clockwise rotation of 35° occurred, which is in good agreement with the estimate of rotation of cleavage (see below).

Outside the fault zones, rocks exhibit only a weakly developed spaced (typically at intervals of 2 to 10 cm) cleavage. The cleavage is steeply dipping and generally occurs in conjugate sets. It is interpreted to have formed at an early (pre-faulting) stage of the deformation, and its attitudes are used to constrain motions in the area since formation of the faults.

STATISTICS OF CLEAVAGE

Statistics of regionally distributed cleavage have been made at 24 sites within the fault-bounded blocks. Conjugate cleavages measured from the block northeast of Croydon Creek (Zhang and Hynes, 1991; Figure 1-12-3a in Zhang and Hynes, 1991) show orientations consistent with those to be expected in a stress field due to the initiation of dextral transcurrent motion on the Finlay-Ingenika fault (*cf.* Tchalenko, 1970; Keller *et al.*, 1982; Sylvester, 1988). If the regional cleavage was uniformly distributed before the

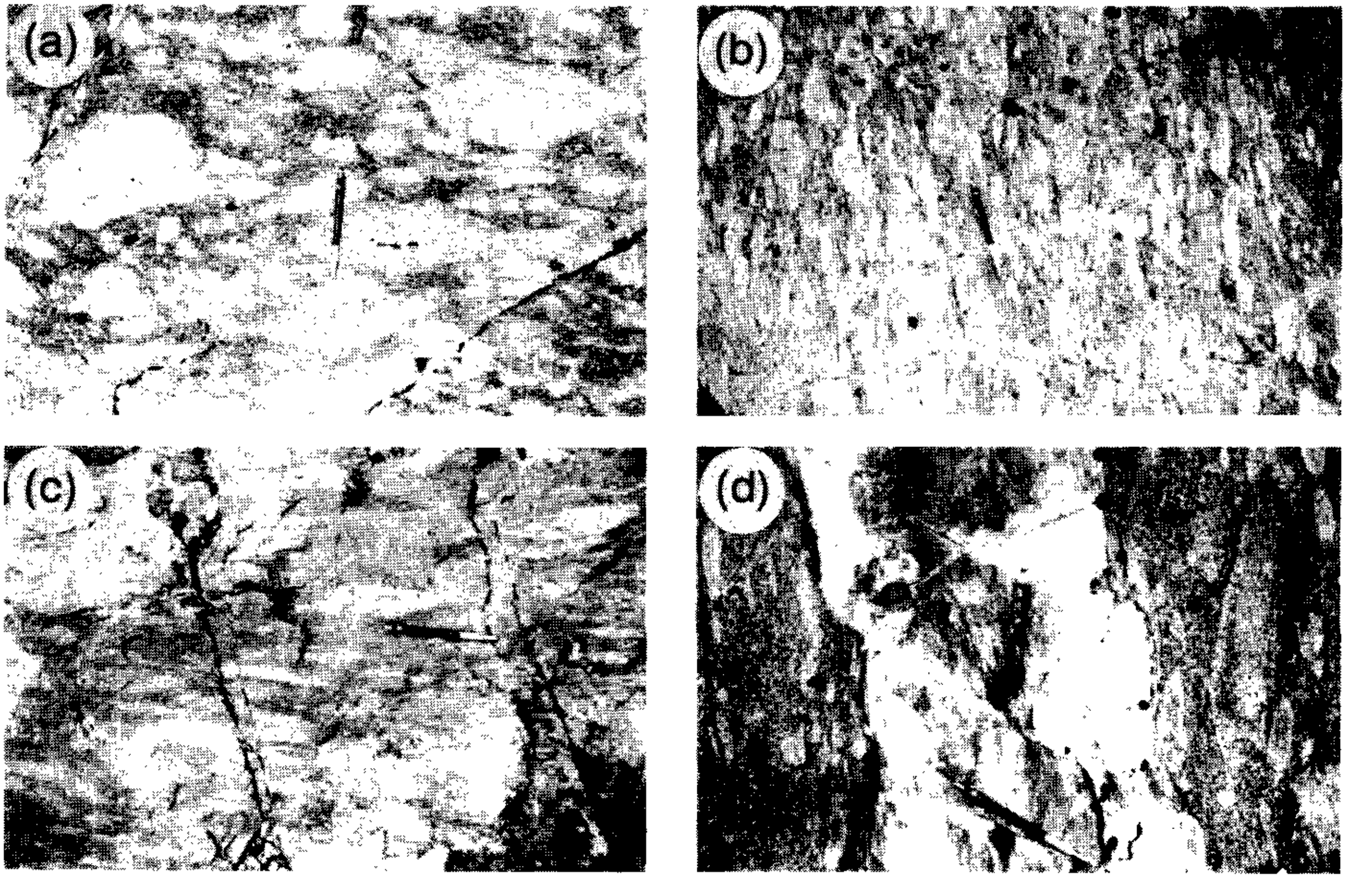

Plate 1-12-2 (a, b and c). Flattened fragments of volcanic breccia moving progressively westwards towards a dextral fault, looking northeast, north-northwest and northeast down, respectively; (d) Deformed mafic dike in the same region as (b), pencil parallel to the shear planes with thrust slip sense, looking north-northwest.

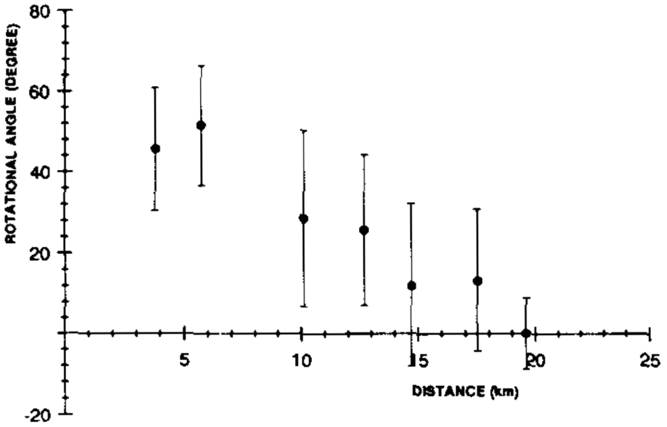

Figure 1-12-4. Variation of block rotational angle with distance away from the Finlay-Ingenika fault. The error bars represent the 95 per cent confidence circles for the rotational angles.

widespread strike-slip faulting in the study area, the variation of orientations of the cleavage can be used to indicate the block rotation. Based on this assumption, the rotational axes and angles for six sites were determined by comparing the mean attitudes for the regional cleavages with those from the block northeast of Croydon Creek. The mean rotational axis is subvertical, and the amount of block rotation varies over the study area, reaching its maximum (51.6±14.9°) close to the Finlay-Ingenika fault and minimum (0.0±9.0°) about 20 kilometres away from the fault (Figure 1-12-4).

CONCLUSIONS

The structures observed along the Finlay-Ingenika fault are dominated by subvertical to vertical, dextral strike-slip faults trending northwest, north-northwest and north-northeast, and sinistral strike-slip faults trending east-northeast. The faults are distributed in a narrow belt, about 30 kilometres wide, adjacent to the Finlay-Ingenika fault. This distribution, together with the attitudes and slip senses of the strike-slip faults, strongly suggests that the deformation developed in association with dextral, transcurrent motions on the Finlay-Ingenika fault. As displacement on the Finlay-Ingenika fault progressed, the deformation was apparently concentrated in the previously formed fault zones, while the fault-bounded, weakly deformed blocks were rotated clockwise about subvertical axes in response to the transcurrent motions. Statistics of regional cleavage indicate that the amount of block rotation varies over the study area, decreasing away from the major fault. This variable rotation of blocks is similar to that described by Nelson and Jones in the Las Vegas Range (1986) and in contrast to the uniform rotation described and modelled elsewhere (*e.g.*, Ron *et al.*, 1986; Hudson and Geissman, 1987; Geissman *et al.*, 1989; Ron *et al.*, 1990). Such rotations may characterize many parts of the Intermontane Belt and could in part explain the apparent disparities between the paleomagnetic declinations observed from the western allochthonous terranes and North America (Monger and Irving, 1980; Irving *et al.*, 1985; Rees *et al.* 1985; Irving and Wynne, 1990). We are currently conducting paleomagnetic studies to test this assertion.

ACKNOWLEDGMENTS

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