Journal of Structural Geology, Vol. 7, No. 1, pp. 57 to 72, 1985
Printed in Great Britain.

0191-8141/85 $03.00 + 0.00

An examination of the cataclastic fabrics and structures of parts of Nisutlin, Anvil and Simpson allochthons, central Yukon: test of the arc-continent collision model

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(*Received* 9 *January* 1984; *accepted in revised form* 4 *June* 1984)

Abstract—Collision of an arc complex against the Yukon part of the North American craton during the Mesozoic resulted in northeastward transport of arc rocks onto the craton. The arc rocks comprise three distinguishable tectonostratigraphic assemblages called: Nisutlin Allochthon, quartz muscovite and chlorite schist derived from sedimentary and intermediate volcanic protoliths; Anvil Allochthon, amphibolite, gabbro, ultramafic rocks and sepentinite; and Simpson Allochthon, granitic and granodioritic rocks and schist derived from them. Deformation, recovery and recrystallization structures show that parts of the allochthons are blastomylonite, formed at temperatures of 350–700°C and at depths between 15 and 40 km. The stacking order of the allochthons is inconsistent and complex, and locally, the cataclastic rocks are overthrust by autochthonous strata. The allochthons are truncated by late steep faults that have mainly strike-slip displacement, and may be contemporaneous with Tintina Fault. The proposed tectonic history of the region is supported by detailed results of the study.

INTRODUCTION

THE GEOLOGY of the Canadian Cordillera can be divided into an eastern, autochthonous North American part, comprising platformal and miogeoclinal strata, and a western allochthonous part, nearly three quarters of the orogen, comprising an amalgamation of terranes accreted in the Mesozoic (Coney *et al.* 1980).

Large-scale post-accretionary shortening by horizontal translation and intra-plate thrusting has been documented along the entire orogen (Monger & Price 1979); however, the overlap of allochthonous terranes over North American strata is only now being recognized as a widespread occurrence. Following the discovery of enigmatic allochthonous assemblages of cataclastic rocks in central Yukon, Tempelman-Kluit (1979) demonstrated tectonic overlap in excess of 100 km of the easternmost accreted terrane onto the margin of the North American craton. Comparable overlap of tectonically equivalent rocks has been reported along strike for more than 1000 km: in northern British Columbia (Gabrielse & Mansy 1980, Gordey *et al.* 1982, Harms 1984), in central British Columbia (Struik 1981), and in southern British Columbia (Read & Brown 1981).

In central Yukon, klippen of cataclastic rocks that lie on comparatively undeformed North American strata root southwestward into a steeply dipping zone of cataclastic mélange called the Teslin Suture Zone (Tempelman-Kluit 1979). The Teslin Suture Zone is interpreted as the former edge of the North American continent (i.e. the Sr^{87}/Sr^{86} line shown in Monger *et al.* 1982). The structural contact between the allochthonous rocks and North American strata, ranging from nearly vertical along the Teslin Suture Zone to nearly horizontal beneath klippen to the east, is interpreted as the tectonic boundary between an accreted arc assemblage and North America (Tempelman-Kluit 1979). However, few detailed observations were available until recently to support this interpretation.

In this paper, the tectonic boundary is described, structural fabrics within the allochthonous rocks are analyzed, an estimate of the physical conditions of deformation and emplacement is offered, and comparisons with other allochthons are made.

TECTONIC SETTING

Central Yukon includes two discrete parts. On the northeast are miogeoclinal strata deposited across the margin of the ancient North American continent; on the southwest is an arc assemblage accreted to North America during the Mesozoic (Tempelman-Kluit 1979, 1981). The assemblage of miogeoclinal strata, ranging in age from Proterozoic to Mesozoic, is dominated by four facies belts of Cambrian to Devonian age (shallow-water carbonate deposits of Mackenzie Platform; shale and chert of Selwyn Basin; carbonate rocks and quartzite of Cassiar Platform; and graphitic shale, siltstone, and quartzite of Nasina shelf) overlain by Carboniferous to mid-Cretaceous strata. The easternmost accreted assemblage includes the arc terrane formed by the Yukon Cataclastic Complex, the Whitehorse Trough, and the Yukon Crystalline Terrane (Tempelman-Kluit 1981); southwest of these are the Coast Plutonic Complex, and other terranes (Fig. 1).

The Yukon Cataclastic Complex contains three assemblages of schistose metamorphosed rocks, the stratigraphic relations, thicknesses and relative ages of which are obscure. Primary layering and other contacts are tectonically transposed and gradational. The rocks range from blastomylonite and ultramylonite to less

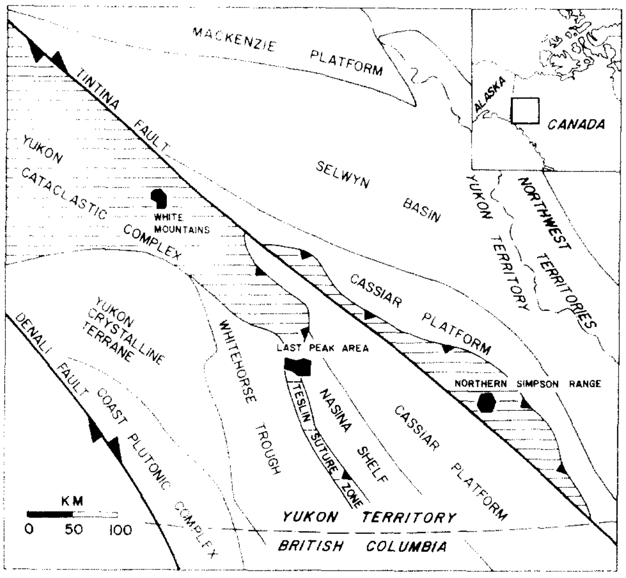

Fig. 1. Tectonic elements of southern Yukon, Canada, after Tempelman-Kluit (1981), and location of the studied areas (black) in the Yukon Cataclastic Complex.

strained equivalents in which the protoliths are locally preserved. These mylonitic rocks form extensive sheets thrust onto strata of the Nasina Shelf and Cassiar Platform (Fig. 1). The Nisutlin Allochthon includes quartz–muscovite schist interleaved with chlorite schist, derived from possibly several sedimentary and volcanic protoliths. The Anvil Allochthon includes amphibolite, gabbro and serpentinite, and is interpreted as sheared ophiolite. The Simpson Allochthon comprises mainly granodioritic rocks and schist derived from them.

The plate-tectonic model proposed by Tempelman-Kluit (1979) involves two major stages: subduction of an ocean basin (Anvil Ocean) along a west-dipping subduction zone at the eastern margin of the arc complex (Stikinia) occurred from Late Triassic through Early Jurassic time; in the Middle Jurassic, arc-continent collision began, culminating in the Late Jurassic and Early Cretaceous with obduction of the arc complex onto the North American craton. The cataclastic rocks of the Yukon Cataclastic Complex and of the allochthons are a structural mélange, and presumably were trench and fore-arc sediments sheared during subduction (Nisutlin Allochthon) and imbricated tectonically with slabs of oceanic crust (Anvil Allochthon) and parts of the arc (Simpson Allochthon) at the face of the arc system. Sheets of cataclastic rocks imbricated with North American strata were transported more than 100 km northeastward of the suture.

The region is divided into three parts by the Tintina and Denali faults, two post-accretionary, right-lateral, strike-slip faults of Late Cretaceous or Tertiary age which localized displacement of approximately 450 and 300 km, respectively (Roddick 1967, Eisbacher 1976, Tempelman-Kluit 1979).

DETAILED GEOLOGY

This study focused on three areas where the three allochthonous assemblages are well exposed (Fig. 1): the White Mountains, the Big Salmon Range near Last Peak, and the northern Simpson Range, a total of approximately 550 km^2. Each area was mapped at

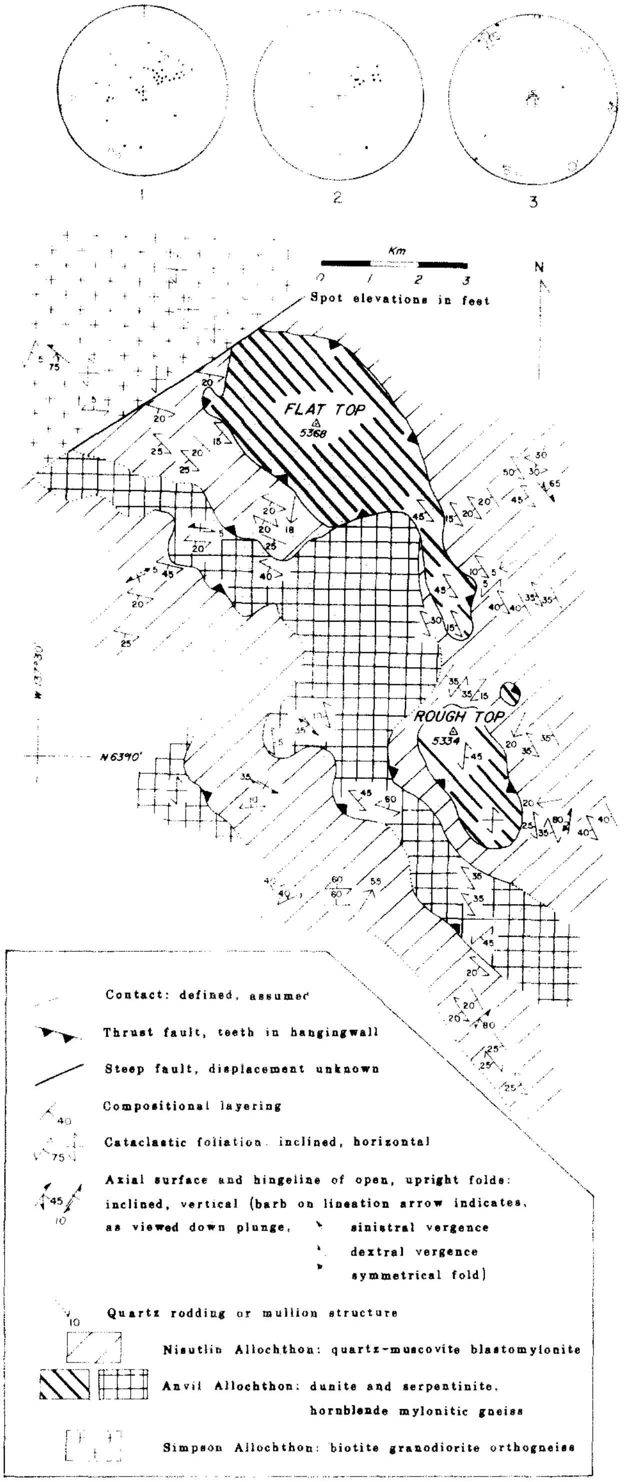

Fig. 3. General geology of the White Mountains. Symbols for the equal-area plots of fabric elements are as follows. Plot 1: poles to cataclastic foliation in Nisutlin and Anvil allochthons (dots, 41 points) and quartz rodding or mullion structure (circles, 5 points). Plot 2: poles to compositional layering in Nisutlin Allochthon (16 points). Plot 3: poles to axial planes of open, upright folds (dots, 7 points, in Nisutlin and Anvil allochthons; triangle in Simpson Allochthon), fold axes of same folds (circles, 7 points, in Nisutlin and Anvil allochthons; hexagon in Simpson Allochthon); fold asymmetry as viewed down-plunge is given by the arrow, symmetrical where arrow omitted; poles to cataclastic foliation in Simpson Allochthon (squares, 7 points).

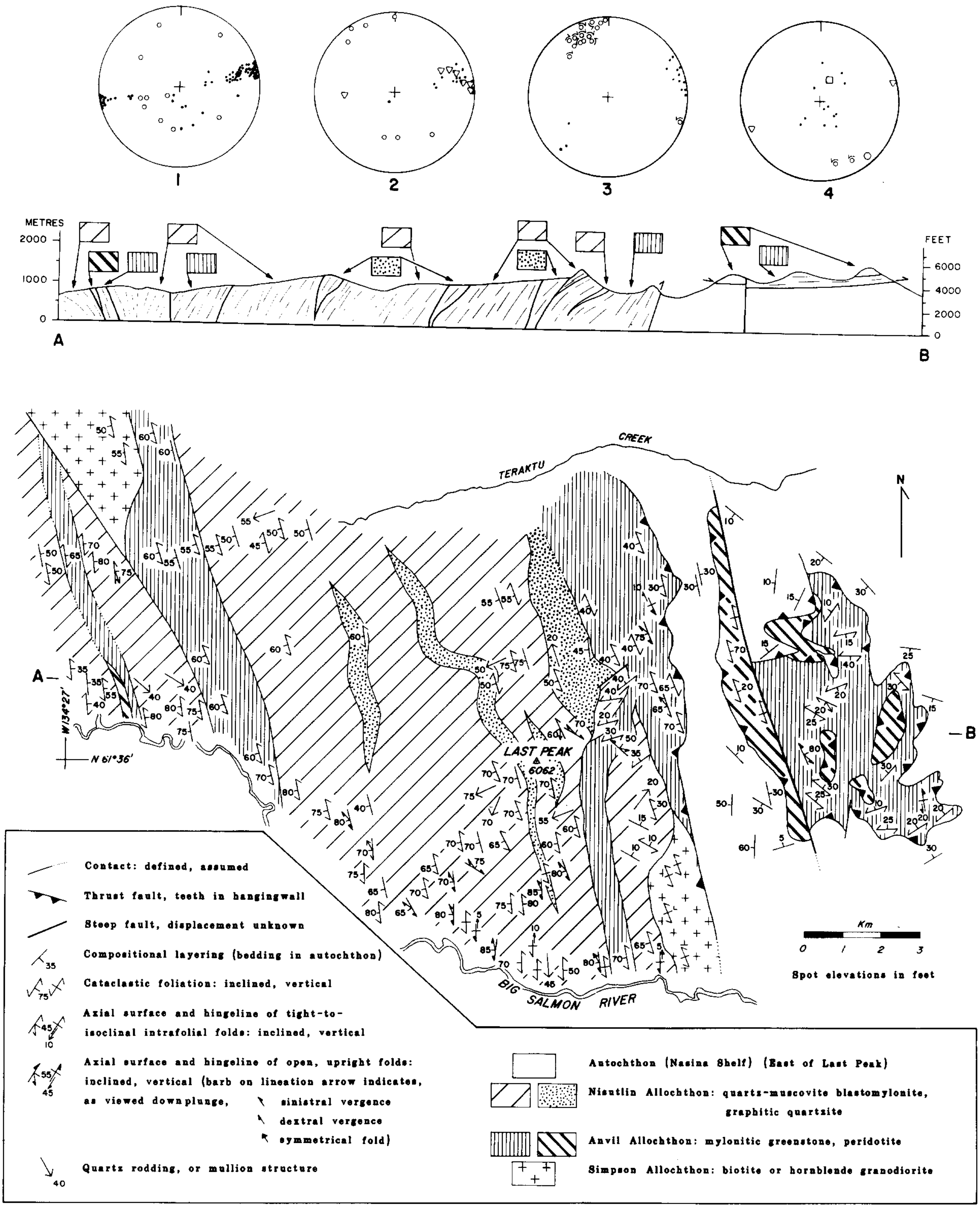

Fig. 4. Generalized geological map and section across the Teslin Suture Zone near Last Peak. The approximate orientation of the main foliation in mylonitic rocks is shown in the cross-section. Symbols for the equal-area plots of fabric elements are (plots 1, 2, 3: Teslin Suture Zone; plot 4: klippe) as follows. Plot 1: poles to cataclastic foliations (dots, 81 points), quartz rodding or mullion structure (circles, 10 points). Plot 2: poles to compositional layering (dots, 16 points), axes of isoclinal folds (circles, 7 points), poles to axial planes of same folds (triangles, 7 points). Plot 3: poles to axial planes of open, upright folds (dots, 15 points), axes of same folds (circles, 15 points; fold asymmetry as in Fig. 3). Plot 4: poles to cataclastic foliation (dots, 12 points), pole to axial plane of isoclinal fold (square), axis of same fold (hexagon), poles to axial plane of open, upright folds (triangles, 2 points), axes of same folds (circles, 2 points, fold asymmetry as in Fig. 3).

1 : 50,000 scale to establish relationships among the three cataclastic assemblages and autochthonous rocks (Erdmer 1981, 1982), and to test results of the earlier reconnaissance mapping (Tempelman-Kluit 1977, 1978a,b) on which the collision model is based.

Rock types characteristic of Nisutlin Allochthon in the mapped areas are dominantly white to pale green muscovite–quartz schist and blastomylonite (Fig. 2; as defined by Higgins 1971), muscovite quartzite, and chlorite–muscovite schist. Rare, fine grained white- to pale gray-weathering marble and fine grained amphibolite are interfoliated with the schist, as well as dark grey to black siliceous graphitic phyllite, graphitic slate, and minor graphitic quartzite. Eclogite lenses are interleaved with these rocks in several localities (Erdmer & Helmstaedt 1983).

Anvil Allochthon comprises the following rock types: garnet–amphibolite grading locally into equigranular garnet–hornblende–oligoclase–quartz rock; medium grained dioritic gneiss and hornblende–biotite schist; medium grained dunite and peridotite that are commonly serpentinized; and dark green, fine grained amphibolite, chlorite–epidote–actinolite (or hornblende) greenstone, and altered basalt. Locally, where quartz is abundant, it has a discontinuous mylonitic or blastomylonitic fabric. Carbonate and quartz pods are common. In places, the mylonite is a flinty-textured streaky rock which grades laterally to crystalloblastic amphibolite.

Simpson Allochthon includes biotite or hornblende granodiorite, quartz monzonite, and related minor subvolcanic rocks. Textures commonly grade from protomylonitic to blastomylonitic along and across the fabric at the centimetre scale; inhomogeneous strain has produced little-deformed domains appearing in plan as narrow augen, separated by dark, anastomosing zones of finer grained material.

In the White Mountains, the dunite and peridotite exposed on Flat Top and Rough Top mountains were originally interpreted as homogeneous masses intruded into the surrounding Klondike Schist (Bostock 1964). Subsequent comparison of these rocks with those of the Simpson Range (approximately 450 km to the southeast across Tintina Fault) suggested the serpentinized peridotite bodies are klippen overlying the Klondike Schist (Tempelman-Kluit 1980). Detailed mapping by the author (Fig. 3) demonstrated that the klippen (Anvil Allochthon) overlie tectonically interleaved subhorizontal slices of muscovite–quartz blastomylonite (Nisutlin Allochthon; the Klondike Schist) and garnet–amphibole mylonitic gneiss (Anvil Allochthon); a steep fault truncates the imbricated slices, placing them against cataclastic granodiorite gneiss (Simpson Allochthon) containing a horizontal fabric.

The Teslin Suture Zone (Tempelman-Kluit 1978a,b) is exposed near Last Peak (Fig. 4); it comprises cataclastic rocks that have a steeply dipping to vertical foliation, exposed in a zone at least 15 km wide containing slices of Nisutlin, Anvil and Simpson allochthons, and possibly of the autochthonous rocks of Nasina facies, tectonically interleaved without any semblance of order. It is interpreted as the boundary between cratonic North America and the arc complex. Across the eastern third of the map area, klippen of Anvil Allochthon comprising slices of serpentinized dunite, and of metamorphosed basalt with a cataclastic fabric, overlie unfoliated graphitic quartzite, shale and limestone of the Nasina facies.

In the Simpson Range, Money Klippe (Tempelman-Kluit 1979) underlies an area of 150 km^2. In the klippe, granitic cataclastite (Simpson Allochthon) generally lies above serpentinite, gabbro and basalt (Anvil Allochthon), and both allochthons rest on siliceous mylonite (Nisutlin Allochthon), forming composite panels in which individual slices may be more than 500 m thick (Fig. 5). Non-cataclastic rocks of North American affinity are presumed to underlie Nisutlin Allochthon. Contacts between the allochthonous slices are generally parallel to the internal strain fabric. Interleaving of the three slices, though uncommon, is more complex than previously thought (see Tempelman-Kluit 1979, p. 9). In an area 60 km to the west, across Tintina Fault, Gordey (1977, 1981) studied several small klippen of Nisutlin Allochthon overlying non-cataclastic miogeoclinal rocks of the Cassiar Platform, in which the structural relationships and fabrics are comparable to those observed here.

MESOSCOPIC FABRIC ELEMENTS

In Nisutlin Allochthon, local distinct fine colour lamination appears to result from compositional layering rather than from original grain size differences, or variable degrees of comminution. This compositional layering is almost invariably parallel to the flaser fabric (cataclastic foliation) defined by subparallel, discontinuous and anastomosing streaks of deformed mica, or by elongate grains of quartz, feldspar, or other minerals, surrounding lenticular domains of granular material. In Anvil Allochthon, the flaser fabric is outlined by streaking in opaque, flinty rock, or by the subparallel orientation of hornblende crystals, or by wispy layers of chlorite, actinolite or epidote, albite and quartz, except in the ultrabasic rocks. In these rocks, a few discontinuous, small schistose zones contain spindle-shaped lenses of dunite which impart a fish-scale appearance to schistosity planes.

The rocks of Simpson Allochthon display a schistosity in a few places; it is defined by the parallel arrangement of platy minerals, by the partial segregation of quartz and feldspar into streaky lenses a few millimetres thick, or by discontinuous, small zones of intense foliation around feldspar augen.

In outcrop and in hand specimen, the cataclastic foliation of Nisutlin and Anvil allochthons is observed in rare, tight to isoclinal recumbent folds, having axial surfaces parallel to the main flaser fabric; only a few tightly appressed fold hinges of this type are preserved, because of extreme attenuation along the foliation and flattening across it. They are variably oriented within the plane of the main foliation.

In all three allochthonous assemblages, the cataclastic foliation is also folded by small, upright, locally asymmetric, open folds (Fig. 6) with amplitudes of up to 50 cm, that overprint the earlier isoclinal folds where both types are developed. Some of these open folds have produced a crenulation schistosity outlined by coarse platy mineral flakes.

In Nisutlin Allochthon, discontinuous quartz rodding, or mullion structure outlined by mica coatings on corrugations of the flaser fabric are developed locally.

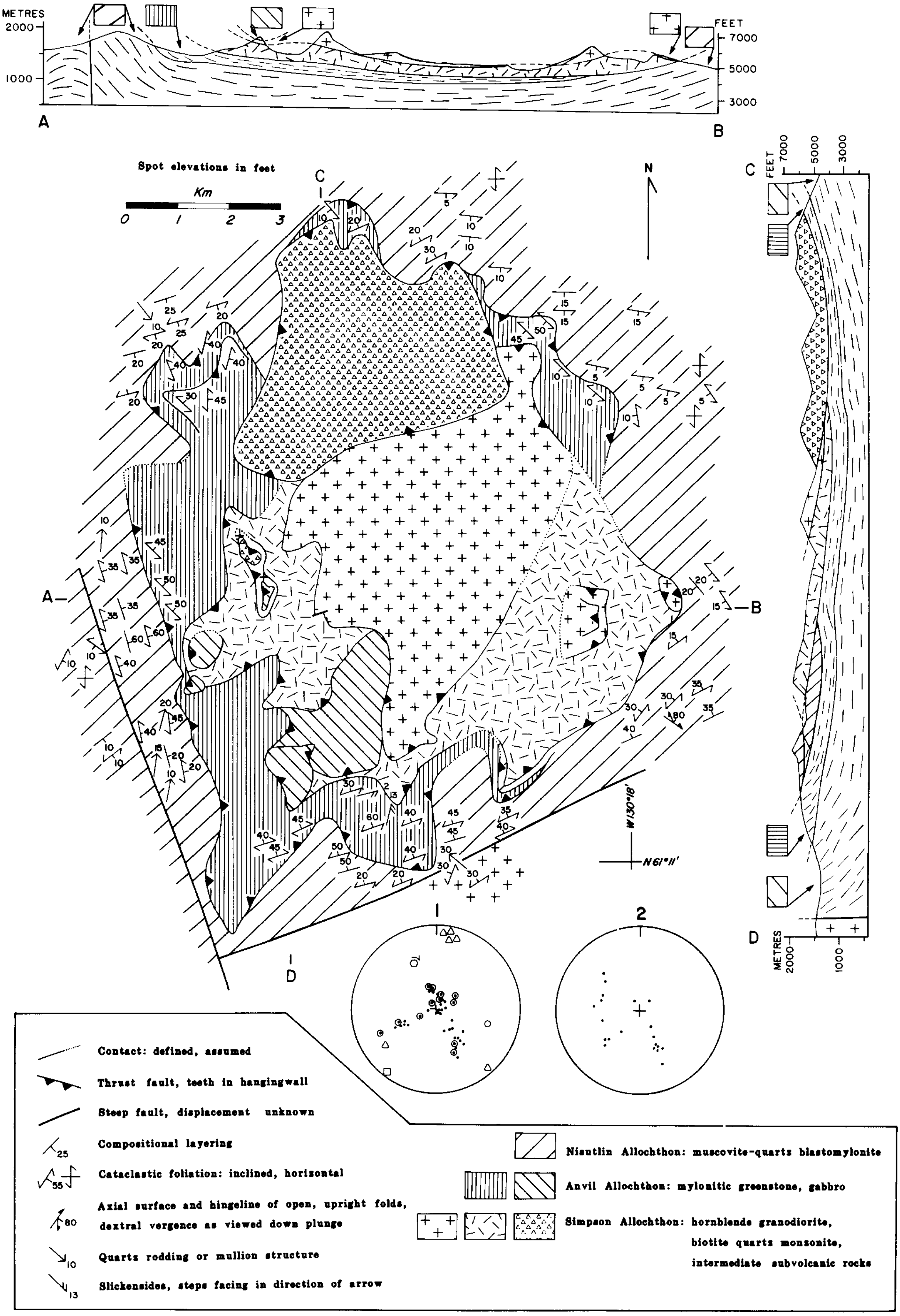

Fig. 5. Generalized geological map and sections of Money Klippe. An indication of the orientation of the main fabric in strained rocks is given in the cross-sections. Symbols for the equal-area plots of fabric elements are as follows. Plot 1: poles to compositional layering in Nisutlin Allochthon (circles, 13 points), poles to cataclastic foliation in Nisutlin Allochthon (dots, 42 points), quartz rodding or mullion structure (triangles, 6 points), pole to axial plane of open, upright fold (square), axis of same fold (hexagon; fold asymmetry as in Fig. 3). Plot 2: poles to cataclastic foliation in Anvil Allochthon (20 points).

THRUST FAULTS

Thrust faults of large displacement separate allochthon from autochthon, and imbricate them. These faults are commonly at a low angle or parallel to the cataclastic foliation above and below them (depending on whether both allochthonous and autochthonous rocks, or allochthonous rocks with large strain differences are juxtaposed). In most instances, the faults are abrupt, gently dipping surfaces, marked locally by less than a metre of slightly recessive sheared rock or, as between the structurally highest slices of Money Klippe, by an abrupt change of rock type across a slickensided, polished surface (Fig. 7). No small-scale interleaving of rock types is visible. These structures can be traced for several kilometres on steep slopes (Figs. 8 and 9). Individual allochthonous sheets separated by these faults may reach thicknesses in excess of 500 m if internal strain is moderate, as in some of the ultrabasic rocks of Anvil Allochthon and in most of the plutonic sheets of Simpson Allochthon.

In the Teslin Suture Zone, contacts between rock types are faults with steep to vertical dips, inferred to be similar to those in the klippen. The complex interleaving and repetition of rock types with varying degrees of strain suggests large displacements along the contact surfaces.

Some thrust faults also carry moderately strained autochthonous rocks over the mylonitic rocks; these are interpreted as basal or late thrusts cutting through ramps, picking up portions of the autochthon in the process. In the klippe east of Last Peak, a fault of this type is a gently dipping, sharp planar surface that is conformable to bedding in the overriding strata. No structural mixing or alteration is visible where the fault is exposed.

STEEP FAULTS

In the three mapped areas, late, steep to vertical faults truncate all three allochthonous assemblages. These faults are younger than the blastesis and the cataclasis in the allochthonous rocks. There is commonly a marked discordance in foliation attitudes on either side of the structures, but minor structures related to the faults are not present.

Map patterns suggest a component of strike-slip displacement near Last Peak (Fig. 4); displacement is indeterminate in other areas. Late steep faults probably exist in the Teslin Suture Zone (Fig. 4), where they may have reactivated older thrust faults, including the eastern boundary of the zone.

The steep northwest-trending fault that truncates the west side of Money Klippe ends at Tintina Fault; as with faults near Last Peak, it may have undergone strike-slip displacement or, alternatively, it may be part of an orthogonal system of normal faults (Tempelman-Kluit 1977).

CATACLASTIC MICROSTRUCTURES

The matrix of strained quartz-rich rocks in the three allochthons is typically finely crystalline. Various amounts of recrystallization have produced a somewhat granoblastic–polygonal texture. The matrix quartz forms elongate grains or grain aggregates with both a dimensional preferred orientation and a lattice preferred orientation.

Nisutlin Allochthon

The schistose rocks of Nisutlin Allochthon have a strong, somewhat irregular foliation. They are mainly crystalloblastic, and their streaky fabric is commonly obscured in hand specimen by recrystallization. The flow structure in the foliation also results from the variable size reduction of quartz grains, comminuted mica grains, and the alignment of feldspar augen. Quartz has a number of characteristic habits which indicate its deformation. Generally, it occurs as equant (Fig. 10) or slightly elongate small grains (less than 50 μm). Polygonized subgrains, some with 120° triple junctions, are common in the interior and along the rims of larger quartz grains. Larger, irregular grains with undulose extinction and serrated rims are elongate parallel to the flow structure. Deformation lamellae are visible in some quartz crystals, larger than 0.1 mm, that occur in discontinuous layers and appear to result from the fragmentation and recrystallization of older quartz ribbons. Rare garnet porphyroblasts in the micaceous layers have straight inclusion trails at a high angle to the foliation. Muscovite and biotite occur as extended, wispy, bent crystals (Fig. 11) bounded by nearly amorphous material. Drawn-out zones of clear quartz grains, larger than the surrounding groundmass, occur along the foliation adjacent to some porphyroclasts; they are interpreted as former pressure shadows. Because the clear quartz within them is extensively recrystallized, only the outlines of the original shadows are easily distinguished; the conspicuous absence of mica, and of dark, nearly isotropic material within these areas is characteristic. This suggests that recrystallization flow succeeded pressure solution as deformation progressed. Feldspar porphyroclasts are commonly surrounded by cryptocrystalline, finely comminuted material which is nearly isotropic.

Anvil Allochthon

In Anvil Allochthon, the largest hornblende crystals are slightly bent and have undulose extinction; some are divided into four or five subgrains, each with faintly undulose extinction. Porphyroclasts of zoisite occur with the hornblende and the garnet. Layers containing variable proportions of quartz, plagioclase and biotite are much finer grained than the hornblende and garnet layers. The minerals in these layers are recrystallized, and original grains of quartz have been reduced to mosaics of subgrains an order of magnitude smaller (20 μm) than the rare amphibole subgrains. A few 120°

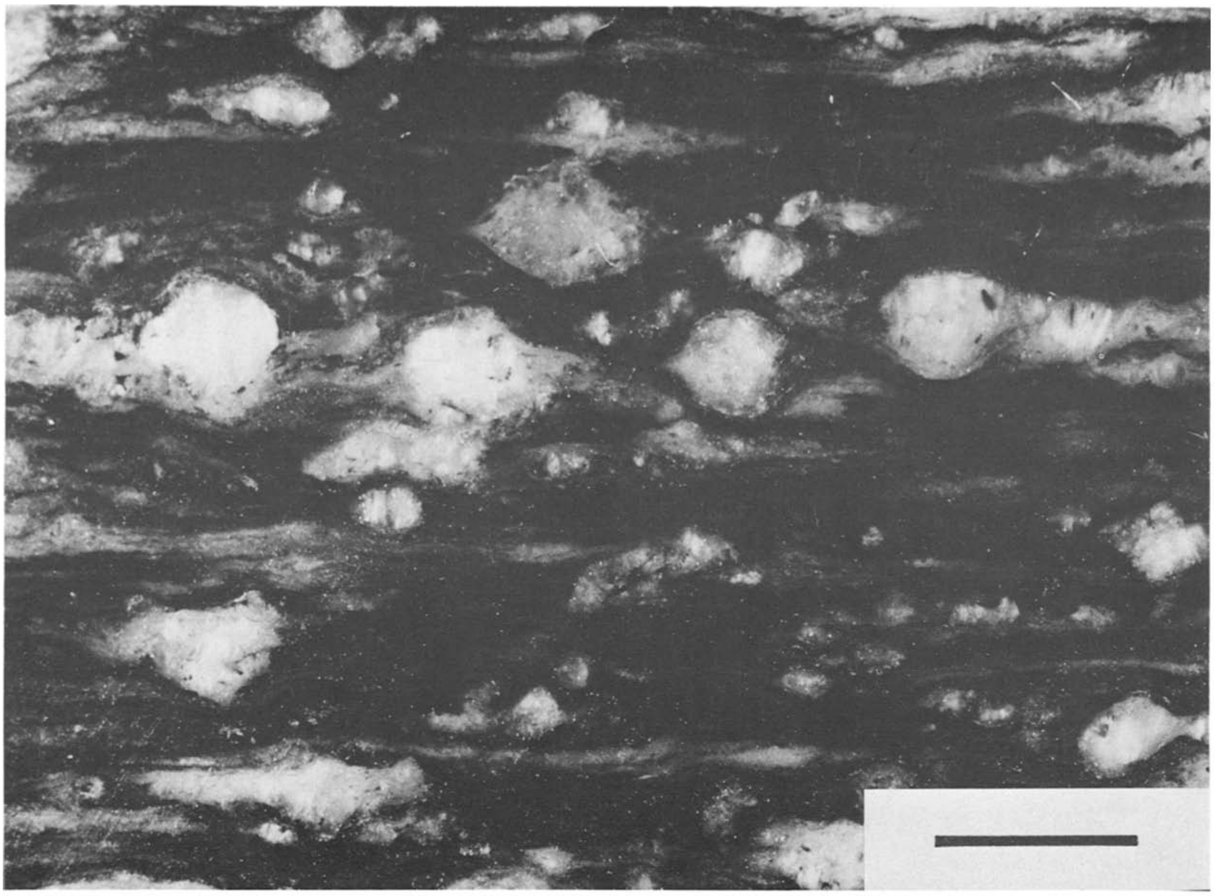

Fig. 2. Sawed surface, normal to the cataclastic foliation, of augen blastomylonite of Nisutlin Allochthon west of Money Klippe. Scale bar 5 mm.

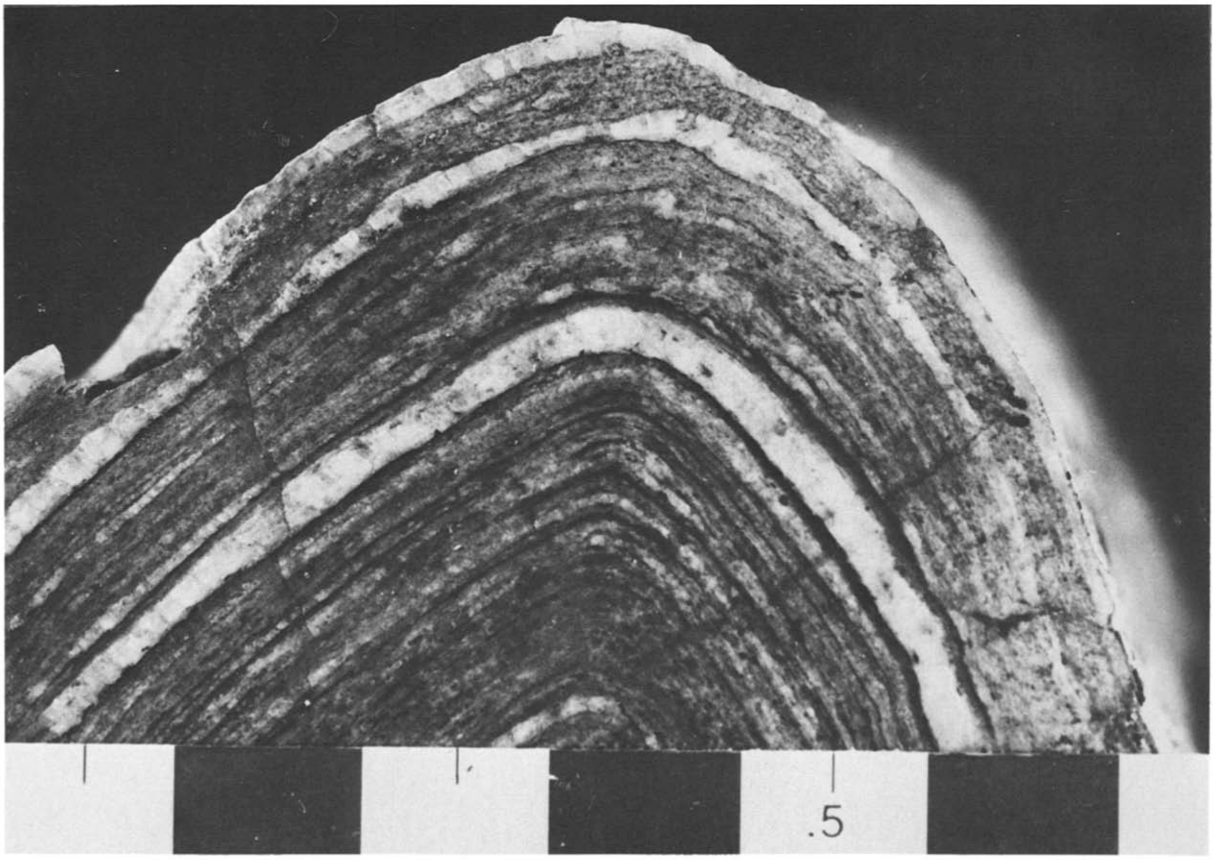

Fig. 6. Sawed surface of blastomylonite of Nisutlin Allochthon from the hinge zone of a small, open fold. Scale in centimetres.

Fig. 7. Contact between quartz monzonite (Simpson Allochthon) and underlying altered basalt (Anvil Allochthon) in the southern part of Money Klippe. The contact is a sharp, clean surface above which the quartz monzonite is saussuritized and chloritized over a few metres. The greenstone is locally serpentinized but not otherwise altered. View to the northwest.

Fig. 8. A thrust slice of gabbro (upper left: "gab"; Anvil Allochthon) overlies a slice of quartz monzonite (centre and upper right: "mon"; Simpson Allochton), and both rest in turn on a slice of altered basalt (foreground: "bas"; Anvil Allochthon) in the southwest part of Money Klippe. Fig. 9 is a view of the mountain face on the right side of the photograph. The arrow points to a white tent. View to the northwest.

Fig. 9. A thrust slice of quartz monzonite ("mon", Simpson Allochthon) lies above altered basalt ("bas", Anvil Allochthon) in Money Klippe. Height of central peak above valley floor is approximately 500 m. View to the northeast.

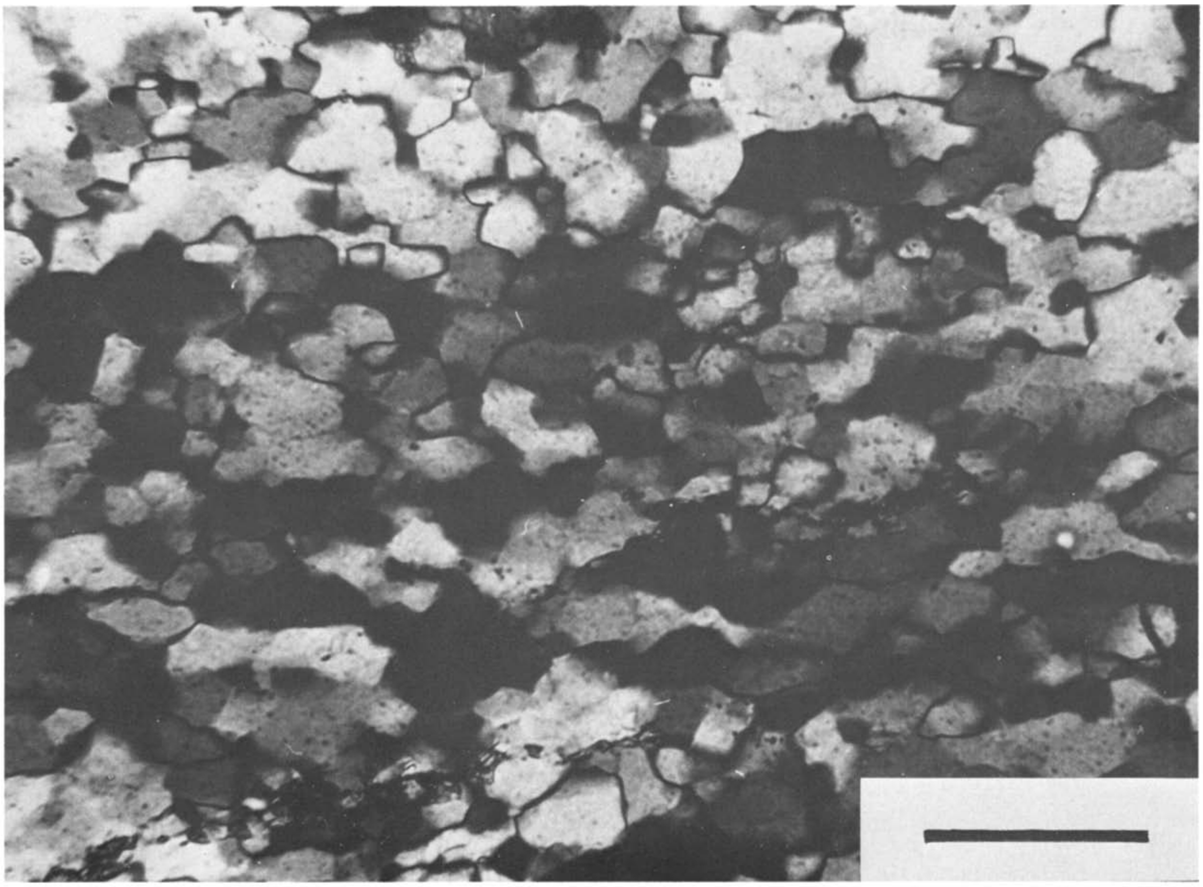

Fig. 10. Recrystallization texture of quartz in blastomylonite of Nisultin Allochthon from the White Mountains. Photomicrograph under crossed nicols. Scale bar 0.1 mm.

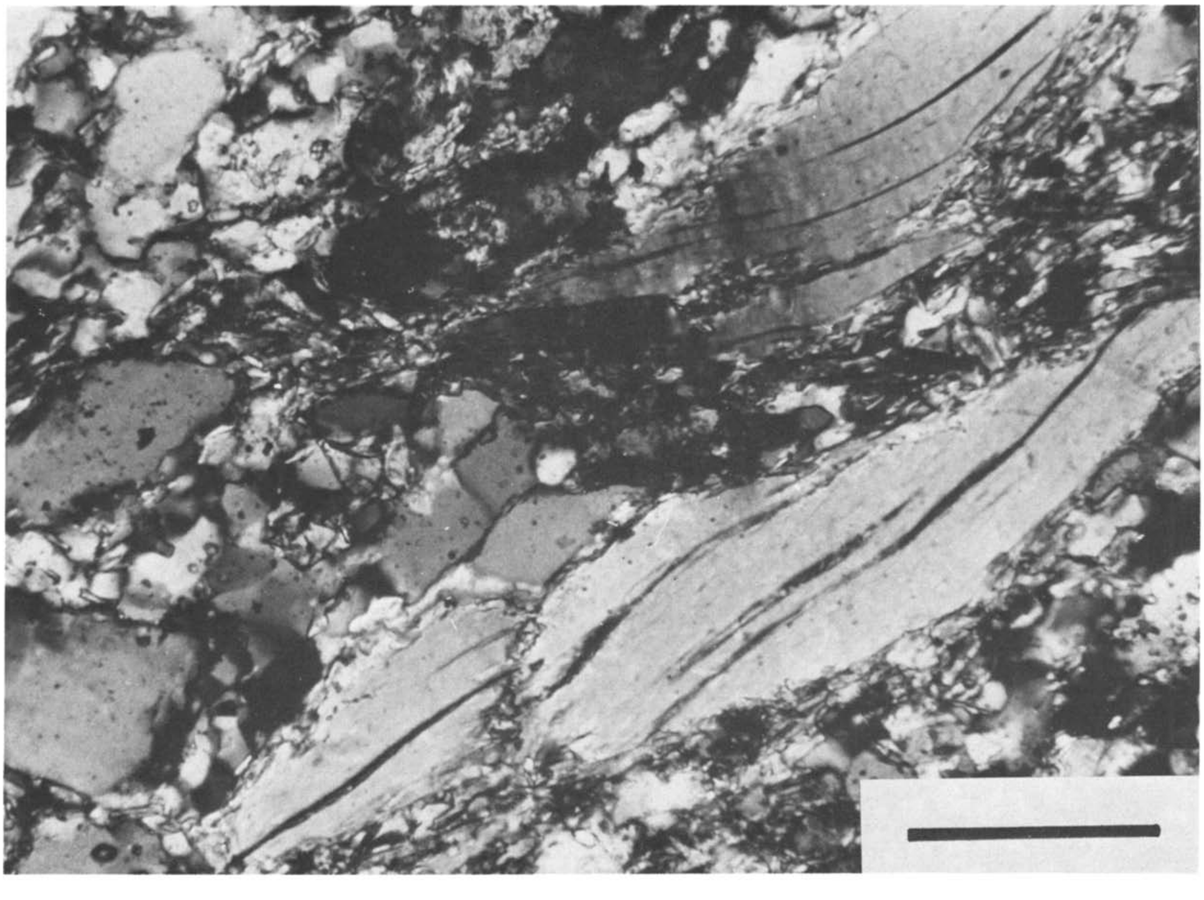

Fig. 11. Bent, lensoid flakes of biotite with serrated edges, surrounded by quartz, in Nisutlin Allochthon near Last Peak. Photomicrograph under crossed nicols. Scale bar 0.1 mm.

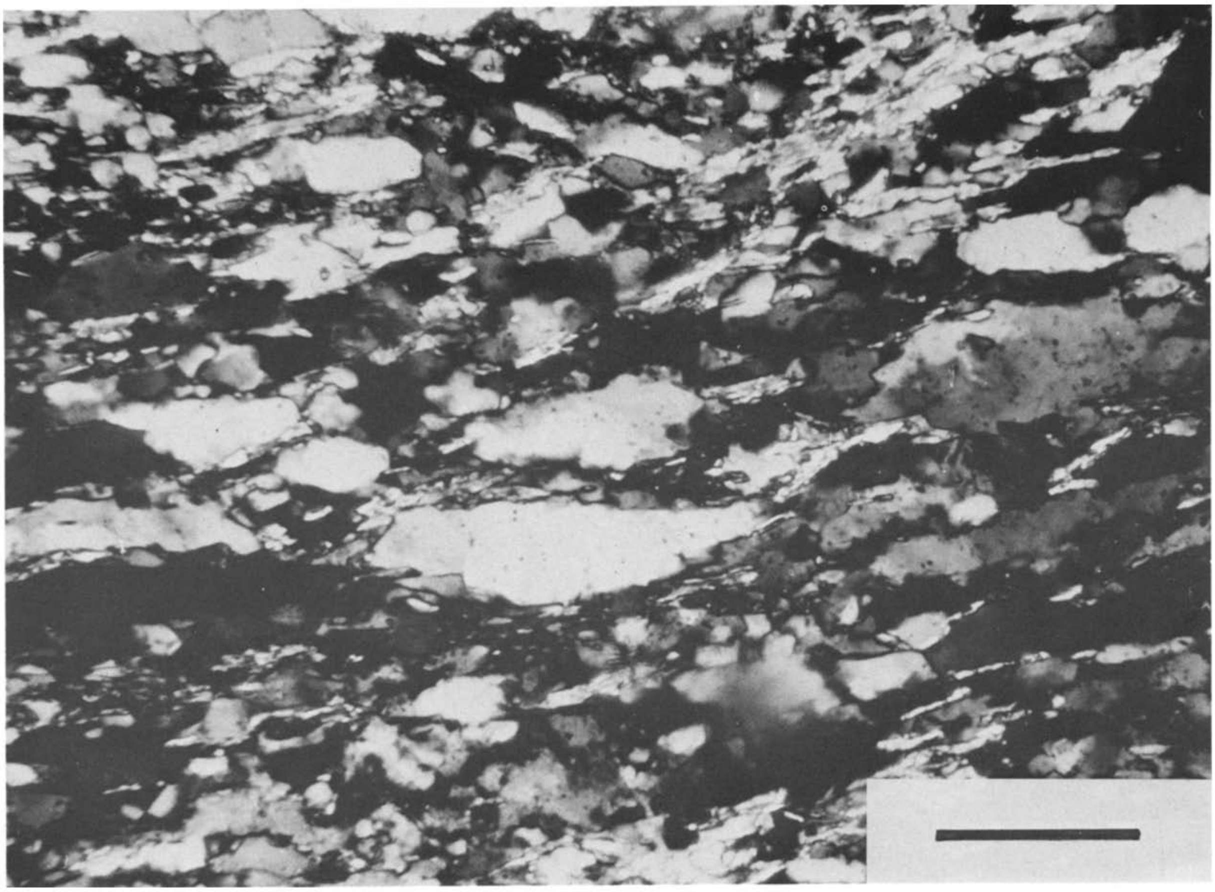

Fig. 12. Recrystallized, elongate quartz and plagioclase grains in mylonitic greenstone of Anvil Allochthon in Money Klippe. Small chlorite and mica flakes separate the grains. Photomicrograph under crossed nicols. Scale bar 0.1 mm.

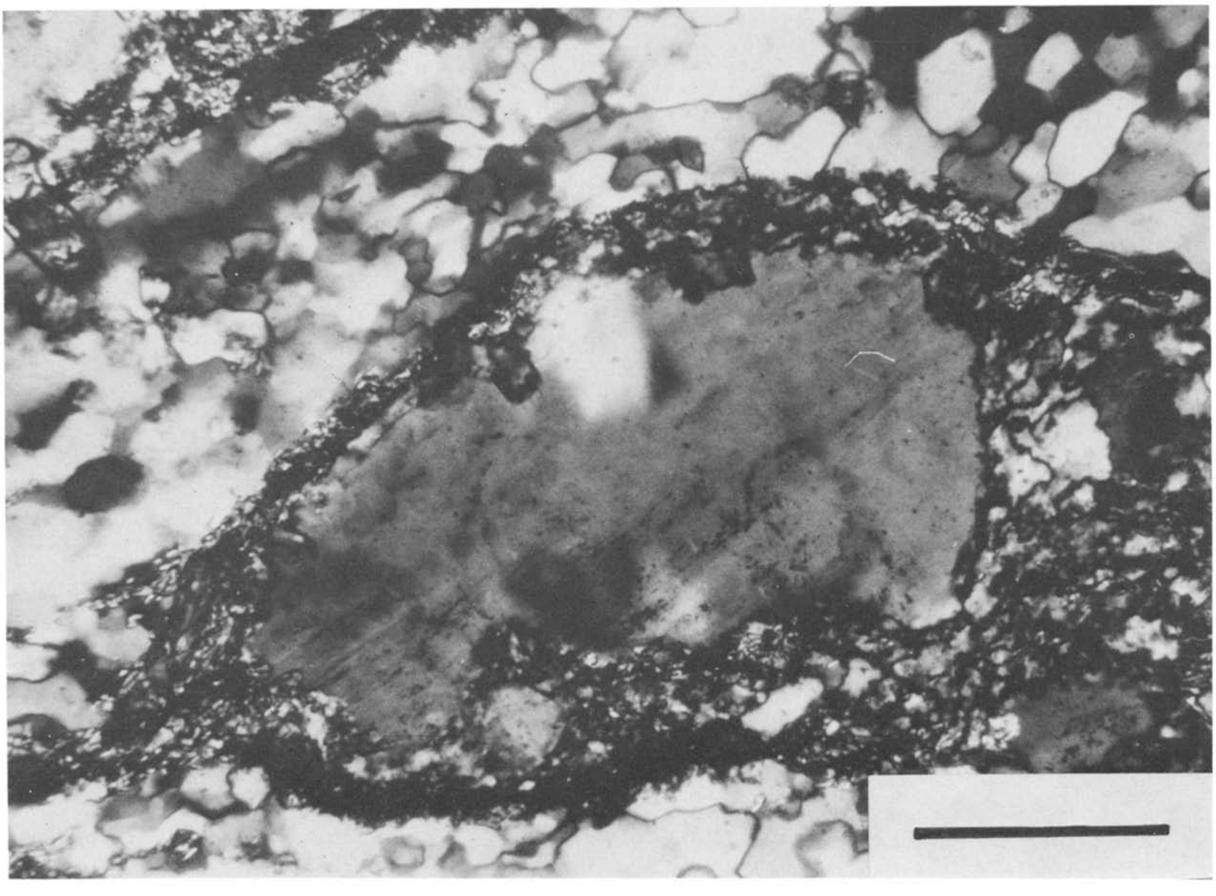

Fig. 13. Grain boundary recrystallization around a plagioclase porphyroclast in mylonitic greenstone of Anvil Allochthon from the White Mountains. Photomicrograph under crossed nicols. Scale bar 0.1 mm.

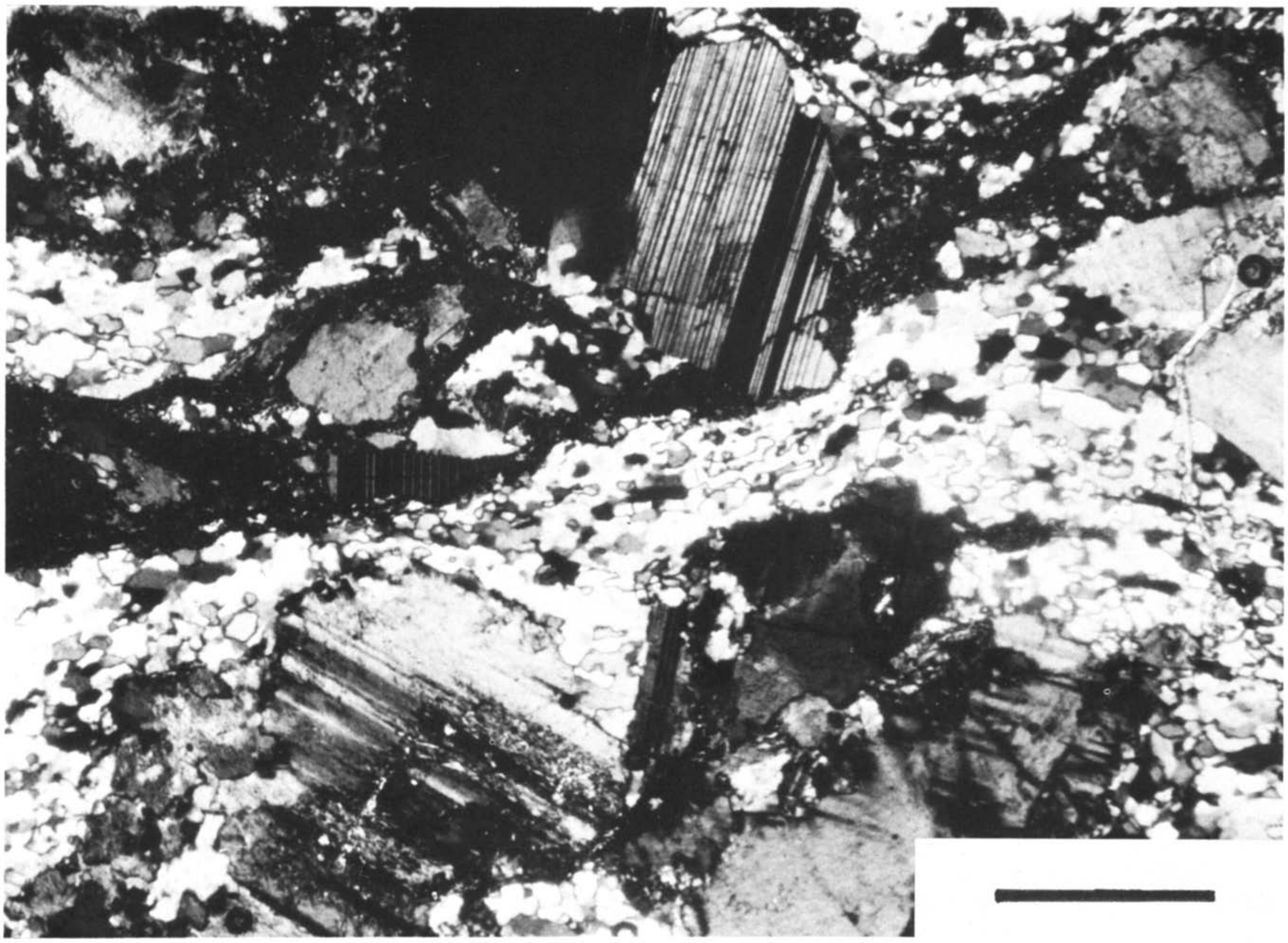

Fig. 14. Texture of mylonitized biotite granodiorite of Simpson Allochthon near Last Peak. Feldspar porphyroclasts appear as islands around which quartz has been extensively reduced in size and recrystallized to outline a flow structure. Photomicrograph under crossed nicols. Scale bar 2 mm.

triple junctions occur, but quartz commonly forms irregular-shaped grains with coarse jagged edges and undulose extinction (Fig. 12), or small clear polygonal grains around large original grains of amphibole or garnet. Twins in plagioclase are slightly bent; some of the crystals are the locus of grain-boundary recrystallization (Fig. 13). Some garnets are boudinaged; the areas between boudins, and pressure shadows of undeformed crystals are filled with finely recrystallized, faintly undulose quartz. Garnet commonly has sigmoidal inclusion trails of clinozoisite, which show up to 360° of rotation, or straight trails at a high angle to the foliation. The sense of rotation of the crystals is not consistent within one thin section. The axes of rotation are approximately parallel; they lie within the plane of the cataclastic foliation, which suggests that at least part of the strain may result from layer-parallel shear. Nearly opaque, streaky, irregular layers of comminuted material (5 μm or less in size) include quartz and epidote. Epidote and albite also occur as porphyroclasts: former pressure shadows and areas between boudinaged grains contain fine recrystallized quartz with 120° triple junctions. Microscopic textures are not conspicuously cataclastic where only mafic minerals are present; this agrees with other observations that mafic rocks rarely display mylonitic texture when sheared together with silicic rocks (e.g. Waters & Campbell 1935).

Simpson Allochthon

In Simpson Allochthon, microscopic textures show a pattern of islands of resistant porphyroclasts surrounded by smaller recrystallized quartz grains. The irregular grains of quartz are less than 0.05 mm across, and form an interlocked border around large original grains of quartz having subgrains with slight orientation differences, or around slightly strained andesine or K-feldspar porphyroclasts up to 2 mm across (Fig. 14). In contrast, other minerals were comminuted and flattened into the plane of the cataclastic foliation. Where no porphyroclasts are present, grains range from equant, with triple junctions (foam microstructure, Kerrich & Allison 1978) to slightly elongate, with even or serrated boundaries. Strongly undulose extinction is rare. The foliation (flow effect) is commonly outlined by grain size variation rather than by mineral segregation. Biotite and muscovite, which occur in spindle-shaped trains of extended crystals, generally have undulose extinction. Quartz in pressure shadows of large porphyroclasts is recrystallized, and the former outline of the shadow is distinguished only by the absence of muscovite. The finest-grained quartz grades into nearly amorphous streaks of fine material parallel to the foliation. Biotite is commonly replaced by chlorite, which occurs in fine grained masses strung out along the foliation.

In Money Klippe (Fig. 5), the degree of cataclasis is substantially less in Simpson Allochthon than in most of the other allochthonous slices; primary igneous textures are preserved.

DISCUSSION AND TECTONIC IMPLICATIONS

The quartz microstructures in the allochthons include deformation, recovery and recrystallization structures, many of which are typical of microstructures formed by plastic flow induced by strong intracrystalline deformation (Bell & Etheridge 1973, White 1976). Quartz is not the only recrystallized mineral: plagioclase, chlorite, epidote, amphibole, carbonate and micas, as well as pyroxene in eclogite, all show dynamic size reduction and recrystallization. However, quartz appears to have deformed preferentially to other minerals, and it generally displays large strains. The microstructures indicate that some of the allochthons were deformed at depth under elevated temperature and pressure (minimum of 350°C and 15 km depth: QP regime of Sibson 1977). This is supported by several minimum temperature estimates of 370–420°C for coexisting biotite and garnet in rocks of Nisutlin and Anvil allochthons in the White Mountains and near Last Peak (Erdmer 1982, Erdmer & Helmstaedt 1983), where metamorphism accompanied cataclasis.

A mylonite zone 15 km wide, such as the Teslin Suture Zone, is not common. This ductile-deformed belt of structural mélange separating distinct terranes is several hundreds of kilometres long. The nature of deformation within the belt (flattening, or shear, or both) is not readily apparent. Some natural mylonite zones are the locus of essentially simple shear (Ramsay & Graham 1970); but in very large mylonite zones, where displacement cannot be established, interpretation is not so clear. Johnson (1967) proposed that the strain could be produced by a flattening normal to the foliation resulting in mylonite layering similar to slaty cleavage. Experimental results (Tullis *et al.* 1973) demonstrated that mylonite textures are produced when there is no rotational component to the displacement; the lamination develops perpendicular to the flattening direction. The microstructures result only from the large finite strain during axial compression. However, a 'space problem' is encountered in applying pure flattening models to field examples (e.g. Escher *et al.* 1975).

Noting that tectonic foliations on a range of scales commonly anastomose in three dimensions while maintaining a planar attitude on average, Bell (1981) proposed that mylonite zones can form by progressive bulk inhomogeneous shortening if the maximum finite elongation plunges approximately down the dip of the foliation. This model offers a possible solution to the boundary problems of bulk shortening for the high strains involved in mylonites, by accommodating coaxial or non-coaxial shortening in discrete high-strain zones with large components of shear. The sense of shear changes along a zone, because the zones of higher strain must anastomose back and forth on a range of scales to remain planar on average. This would produce the lensoid pods of relatively unstrained material between zones of intense deformation observed at many scales in the allochthons, and would account for the apparently inconsistent rotation directions in garnet porphyroclasts.

Quartz rodding in the strained rocks may be parallel to the locally dominant direction of maximum elongation during cataclasis, and the S trails in garnet may be perpendicular to that direction, but their rarity and dispersion suggest that they have been affected by later strain, and that they do not reflect the latest slip direction or the overall direction of tectonic transport.

The tight to isoclinal folds may have developed from more open folds during the early phases of mylonitization, and may have been rotated towards the direction of tectonic transport, as proposed by Bryant & Reed (1969) for mylonite zones of the southern Appalachians. Formation of the open upright folds postdates the recumbent isoclinal fold event and the imbrication and interleaving of the cataclastic rocks, and probably results from final emplacement. Their dominant asymmetry and orientation in klippen and in the Teslin Suture Zone (Gordey 1981, Erdmer 1982) suggest a relative overriding to the northeast (Figs. 3–5), and fully support the hypothesis that the Teslin Suture Zone is the root of the klippen. The slickensides in the higher slices of Money Klippe also suggest northeast transport, if steps on the slip surface are assumed to face in the direction of transport.

The zones of shear strain within the Teslin Suture Zone are essentially parallel to its boundaries: the angle between the boundaries of a shear zone and the foliation within it decreases as the foliation is rotated towards parallelism with the zone boundaries (Ramsay 1980). These boundaries would become eventually normal to the direction of maximum shortening, and the high strain would appear as a flattening normal to the foliation. Thus, both a local flattening fabric and shear deformation on a large scale are compatible with the present geometry of the Teslin Suture Zone and with the fabrics in the allochthons.

The stacking order of the allochthons is much more complex than previously thought. The observation that less deformed autochthonous rocks clearly overlie cataclastic rocks in places suggests that horses, or duplexes, developed along the major thrusts. It also suggests that slices of the old North American margin were tectonically involved at various stages of the cataclasis, and are now preserved in Nisutlin Allochthon (graphitic quartzite layers of Nisutlin Allochthon, which would have originated on Nasina Shelf). The apparently consistent ascending order of stacking proposed by Tempelman-Kluit (1979; Simpson Allochthon resting on Anvil Allochthon, Anvil Allochthon resting on Nisutlin Allochthon) cannot be supported in any of the map areas (e.g. Figs. 3–5), and is probably an oversimplification for the rest of the Yukon Cataclastic Complex.

The simplest geological situation accounting for the proposed combined shear and flattening mechanism, and for the complex stacking, is the collision of an arc with the passive western North American margin, as proposed by Tempelman-Kluit (1979). From the present study, in addition to the detailed refinements noted above, the physical conditions of deformation in the collision zone can be directly quantified. The enclosed eclogite assemblages, formed 'in situ' with their immediate host rocks (Erdmer & Helmstaedt 1983), show that parts of the structural mélange were brought from surface conditions to pressures greater than 12 MPa and temperatures above 650–700°C, and deformed in this environment. Because of the rarity of indicators of such extreme conditions, only a small volume of the exposed rocks can be shown with certainty to have been buried to, and brought up from, such depths (40 km); however, as most of the allochthons are blastomylonite, most of their protoliths were buried to at least 15 km depth. The rocks were deformed during and after their peak metamorphism, before being interleaved with less-deformed parts of their protoliths, assembled into composite crystalline sheets, and obducted onto the continental margin. As footwall rocks have open folds and no strong strain fabric, it is clear that most of the strain predates allochthon emplacement and was acquired during the formation of the structural mélange.

Simultaneous deformation at many levels of a steeply dipping mylonite zone at least 40 km deep (the Teslin Suture Zone) produced the variety of strains (and metamorphic minerals) in the allochthons. This variety results from a 'sampling' of P–T conditions ranging from shallow, low-strain regions (some slices of Simpson Allochthon, and of the North American edge), through intermediate and deep regions (mylonitic rocks in various states of strain), to the deepest regions documented by metamorphic minerals (at least 40 km, as indicated by the eclogites). The physical conditions of nearly all levels of a zone of subduction and collision are represented.

Comparisons of the Yukon allochthons with other regions show that there are some notable differences. The most striking is the involvement of large volumes of granitic and granodioritic rocks in the thrusting: for example, there are no flat thrust sheets of unstrained, arc-derived, granitic rocks in the imbricate series of nappes exposed today in the Alps (e.g. Roeder & Bögel 1978, Trümpy 1980). These granitic thrust sheets show the same low internal strain as many large obducted ophiolite slabs; the mechanics of their emplacement, as proposed for some ophiolite slices by Elliott (1976), may be no different than those of thrust sheets in a foreland thrust belt.

Only a few of the many worldwide ophiolite slabs that are interpreted to result from collision between a passive margin and an island arc have other allochthons overlying them. Well exposed examples are the Oman (e.g. Gealy 1977) and Newfoundland (e.g. Dewey and Bird 1971) allochthons. In both these regions, non-ophiolitic sheets above the ophiolite either display a narrow range of rock types (such as the calcareous and clastic sheets of the Batinah Complex: Woodcock & Robertson 1982), or, where rock types are more diverse, are stacked in a consistent order in which sheets become younger structurally downward and across the complex, reflecting the peeling of successively landward sections from the leading edge of the subducting plate (e.g. the consistent succession of the Humber Arm to Bay of Islands slice assemblages: Williams 1975). In the Yukon, the ophiolite assemblage is tectonically dismembered, and ophiolitic, granitic, and siliceous mylonite sheets are interleaved into complex and inconsistently arranged stacks. The accretionary process was neither orderly nor progressive; metamorphic mineral assemblages show that some of the structural slices were repeatedly strained before final emplacement (Erdmer & Helmstaedt 1983). The juxtaposition of rocks from such contrasting environments, and displaying such an array of strains, appears unique; it is characteristic of the boundary of the easternmost accreted terrane of the northern Cordillera, and provides a basis for documenting the collision of progressively more outboard terranes in the accreted portion of the orogen.

CONCLUSIONS

Nisutlin, Anvil and Simpson allochthons are portions of a volcanic–plutonic arc complex thrust onto the North American craton during the Mesozoic. They can be correlated between map areas, and are differentiated on the basis of lithology: Nisutlin Allochthon comprises siliceous metasedimentary and intermediate volcanic rocks, and represents sediments and arc volcanics sheared during subduction and obduction; Anvil Allochthon comprises basaltic and ultramafic rocks, and represents slices of oceanic crust; and Simpson Allochthon comprises granitic and granodioritic rocks representing the subvolcanic part of the arc edifice. These distinctive tectonostratigraphic assemblages can be recognized along the entire length of the Teslin Suture Zone, indicating that the collision between arc and continent affected most of the Yukon cratonal margin.

There is a pervasive flow-structure layering; original layering is rarely preserved, having been transposed as discrete slip surfaces. Some thrust slices of plutonic rocks show no internal strain, a result perhaps of relatively brittle or strongly heterogeneous strain. The rocks are blastomylonites; cataclasis involved recrystallization flow in response to simple shear and flattening within a large zone of ductile deformation, at various crustal levels up to 40 km deep. Once emplaced, the allochthons were cut by late steep-dipping faults, some of which may be contemporaneous with movement on the Tintina Fault. They record a late phase of brittle deformation, more extensive that previously recognized.

Thrusting of autochthonous strata together with the cataclastic rocks resulted from the involvement of the North American miogeocline in the arc-continent collision. The juxtaposition of such distinct tectonostratigraphic assemblages, the large strain contrasts within and between slices and assemblages, and the array of metamorphic conditions recorded in the rocks all support the proposed model of evolution.

Acknowledgements—The results summarized here derive from part of a Ph.D. study at Queen's University in Kingston, under the guidance of H. Helmstaedt and during the tenure of Natural Sciences and Engineering Research Council scholarships and Queen's graduate awards. Field work was carried out with the logistical support of the Geological Survey of Canada's Cordilleran Geology Division, and of the Geology Section of the Department of Indian and Northern Affairs in Whitehorse. D. Tempelman-Kluit's field visits and support since 1979 are acknowledged with thanks. Constructive reviews of the original manuscript were provided by R. G. Anderson, R. I. Thompson, and anonymous reviewers.

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