Tectonic significance of Late Paleozoic deformation in the Cape George Peninsula, Antigonish Highlands, Nova Scotia

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Late Paleozoic deformation of the Cape George Peninsula, Antigonish Highlands, Nova Scotia, provides information on post-accretionary fault movements associated with waning stages of Appalachian orogenic activity. Anomalously intense brittle to ductile deformation of the low-grade Late Paleozoic rocks of the peninsula occurred along east-west shear zones in a ca. 4 km-wide belt bounded by the NE-trending Hollow and Greendale faults. Deformation adjacent to, and between, these two faults resulted in brecciation, folding and thrusting, the development of slickensides on major dislocation surfaces, the local development of S-C fabrics and stretching lineations defined by elongate pebbles, and/or the production of extensional fractures and veins. The data suggest dextral and subordinate thrust components of movement along the east-west shear zones. Deformation is attributed to dextrally oblique compression between the bounding Hollow and Greendale faults along which significant reverse displacements are proposed on the basis of fault geometry and kinematics. The Cape George Peninsula is interpreted as a "pop-up" structure between these back-to-back oblique-slip reverse faults and is considered to occupy a strongly transpressive step-over zone between them. The east-west shear zones, which record dextral transpressive motion and steepen towards the north in a positive half-flower structure configuration, are parallel to Reidel R-shears of the shear fracture array and are interpreted to be transfer faults within the step-over zone along which oblique slip with dextral and reverse components of motion was transferred from the Hollow Fault to the Greendale Fault. Development of the regional stress regime required by these fault kinematics is consistent with coeval post-accretionary dextral motion between the Meguma and Avalon composite terranes along the east-west Cobequid-Chedabucto fault system.

La déformation du Paléozoïque tandif de la péninsule de Cap George, dans les hautes terres d'Antigonish en Nouvelle-Écosse, fournit des informations sur les mouvements de failles post-accrétionaires associés aux stades terminaux de l'activité orogénique appalachienne. Une déformation fragile à ductile anormalement intense des roches du Paléozoïque supérieur de faible grade s'est produite le long de zones de cisaillement est-ouest dans une ceinture d'environ 4 km de largeur limitée par les failles de Hollow et de Greendale d'orientation nord-est. La déformation adjacente et entre ces failles a résulté en de la bréchification, du plissement et du chevauchement, le développement de slickensides sur des surfaces de dislocation majeures, le développement local de fabriques C-S et de linéations d'étirement définies par des cailloux allongés, et/ou la production de fractures et de veines d'extension. Les données suggèrent des composantes de mouvement dextres et, dans une moindre mesure, de chevauchement le long des zones de cisaillement est-ouest. La déformation est attribuée à une compression dextre oblique entre les failles limitrophes de Hollow et de Greendale le long desquelles des deplacements inverses importants sont proposés sur la base de la géométrie et de la cinématique des failles. La péninsule de Cap George est interprétée comme une structure d'extrusion verticale entre ces deux failles obliques à mouvement inverse, dos à dos, et est considérée comme occupant une zone de recouvrement fortement transpressive entre elles. Les zones de cisaillement est-ouest, qui montrent un mouvement de transpression dextre et deviennent plus abruptes vers le nord en une configuration de demie "flower structure" positive, sont parallèles aux riedels synthétiques du réseau de fractures de cisaillement et sont interprétées comme étant des failles de transfert à l'intérieur de la zone de transfert suivant lesquelles un mouvement oblique avec des composantes de mouvement dextre et inverse furent transférées de la faille de Hollow à la faille de Greendale. Le développement du régime de contrainte régional requis par ces cinématiques de failles est en accord avec un mouvement post-accrétionaire dextre entre les terrains de Meguma et d'Avalon composite le long du système de faille est-ouest de Cobequid-Chedabucto.

[Traduit par la rédaction]

INTRODUCTION

The Cape George Peninsula in the northern Antigonish Highlands (Fig. 1) forms the prominent northeastern corner of mainland Nova Scotia. The peninsula is underlain by Late Precambrian and Ordovician to Devonian-Carboniferous rocks which locally display intense deformation adjacent to major faults (Barnhill, 1980; Nance, 1980), the kinematics of which are related to the waning stages of Appalachian orogenic activity.

The Appalachian orogen in mainland Nova Scotia is divided into two lithotectonic belts (inset, Fig. 1), the Avalon composite terrane to the north and the Meguma terrane to the south (Williams and Hatcher, 1982; Keppie, 1985). The intervening terrane boundary is the major east-west trending Cobequid-Chedabucto fault system, of which the on-land

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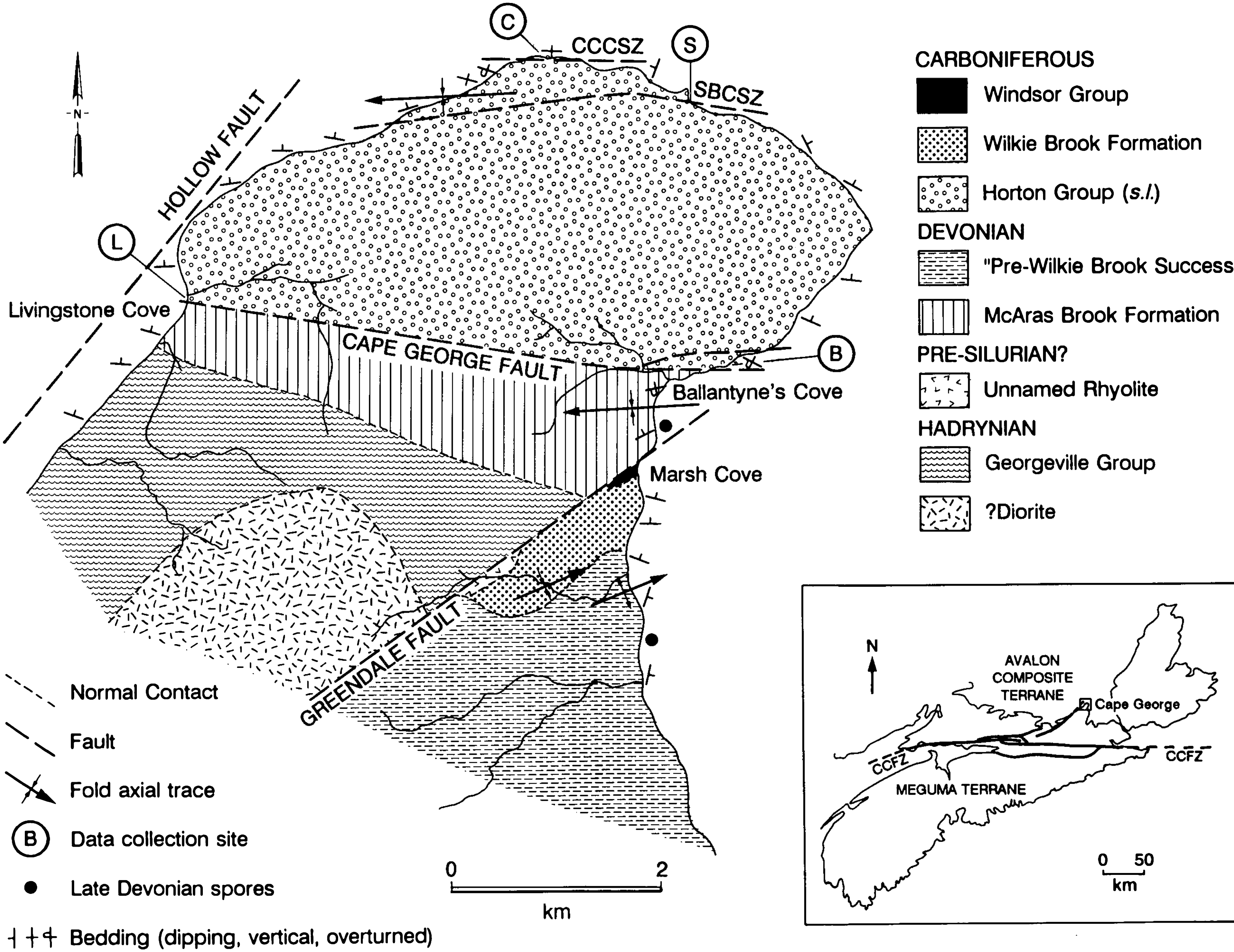

Fig. 1. Simplified geological map of the Cape George Peninsula (modified after Boucot *et al.*, 1974; Keppie *et al.*, 1978 and Bruck *et al.*, 1985). Marsh Cove Limestone is shown as Windsor Group in legend. CCCSZ - Cormorant Cliff Cove shear zone, SBCSZ - School Brook Cove shear zone. Inset shows location of the study area and the Cobequid-Chedabucto fault system (CCFS).

trace is over 300 km long (Mawer and White, 1987). Also known as the Minas Fault Zone (Keppie, 1989), this anastomosing fault system extends from the Minas Basin in the west to Chedabucto Bay in the east and is associated with a clockwise rotation of the generally northeasterly trending structural grain of the Appalachian orogenic belt. $^{40}Ar/^{39}Ar$ dating of the oldest preserved metamorphic fabrics thought to be related to the accretion of the Meguma and Avalon composite terranes yields 400 to 415 Ma ages (Keppie and Dallmeyer, 1987). The fundamental fault systems along which Late Paleozoic deformation took place must, therefore, have existed since at least this time. An upper age limit of accretion is provided by Late Devonian or Early Carboniferous overstep of the Horton Group across the terrane boundary.

Kinematic indicators from (a) ductile fault-related fabrics overprinted by later brittle fabrics in rocks of the Meguma and Avalon composite terranes (Mawer and White, 1987), (b) fault-related fabrics in Devonian-Carboniferous plutons in the Meguma terrane (Dallmeyer and Keppie, 1987; Hill, 1988), and (c) intense local Late Paleozoic ductile deformation in Avalonian rocks adjacent to the Avalon-Meguma terrane boundary (Keppie, 1982a; Donohoe and Wallace, 1982; Yeo and Gao Ruixing, 1987; Waldron *et al.*, 1989) suggest a protracted history of predominantly dextral movement from the time of accretion until the Late Carboniferous. Several hypotheses for the tectonic setting of Late Paleozoic rocks in Maritime Canada have been proposed that involve the development of pull-apart structures (Webb, 1969; Bradley, 1982), extensional collapse (Lynch, 1992; Lynch and Tremblay, 1992), and foreland basins (Keppie, 1992). However, a fuller appreciation of the regional tectonic significance of this interaction requires comparative kinematic studies of Late Paleozoic successions with increasing distance from the terrane boundary.

Deformation of Late Paleozoic overstep sequences, such as those on Cape George, provides important tectonic and kinematic constraints for post-accretionary movement on faults associated with the Cobequid-Chedabucto fault system. In this study, we describe the kinematic history of the Cape George Peninsula based on the geometry of fault-related fabrics developed within major shear zones. We then use the data to evaluate the regional tectonic setting of the peninsula between major NE-trending faults active during post-accretionary east-west dextral motion on the Avalon-Meguma terrane boundary.

Geological Setting

Regional geology

Late Paleozoic rocks in the Appalachian orogen of Maritime Canada are characteristically low-grade, mildly deformed and gently folded, continental to shallow marine deposits up to 10 km thick. The Carboniferous stratigraphy is characterized by sharp and profound changes in thickness and facies (Schenk, 1969), thought to be related to a complex of depocentres within the regionally extensive Maritimes Basin (e.g., Boehner, 1986; Gibling *et al.*, 1992). These sedimentary sequences include (a) Middle Devonian to Early Carboniferous non-marine clastic sedimentary rocks generally assigned to the Horton Group, (b) the Early Carboniferous continental to shallow marine Windsor Group, (c) the Late Carboniferous sub-aerial Canso, Riversdale, and Cumberland groups, and (d) the Late Carboniferous to Permian, primarily fluvial, Pictou Group (Keppie, 1982b; Donohoe and Grantham, 1989). These intra-continental sedimentary rocks were deposited in progressively subsiding sub-basins throughout the Late Paleozoic, and were derived from marginal fault scarps and intrabasinal horsts (e.g., Schenk, 1969).

Middle Devonian to mid-Carboniferous portions of the stratigraphy are locally interlayered with bimodal volcanic successions. The geochemistry of these volcanic rocks, and that of coeval plutonic rocks in the Cobequid Highlands (Pe-Piper *et al.*, 1989), is consistent with an intra-continental rift setting which is inferred to have accompanied strike-slip motion on major faults within the Maritimes Basin during the transpressive stage of the Acadian orogeny (Keppie, 1982b; Dostal *et al.*, 1983). Adjacent to these faults, such as those bordering the Cape George Peninsula, intense brittle to ductile deformation of Late Paleozoic rocks was accompanied by brecciation, folding and thrusting, and the development of S-C fabrics and stretching lineations (e.g., Nance, 1987; Miller *et al.*, 1989; Waldron *et al.*, 1989).

Local stratigraphy

Detailed descriptions of the stratigraphy and structure of the Cape George Peninsula are given in Boucot *et al.* (1974) and Keppie *et al.* (1978). The peninsula is underlain by Late Precambrian and Ordovician(?) to Devonian-Carboniferous rocks which lie between the steep NE-trending Hollow and Greendale faults (Fig. 1).

Ordovician(?), Silurian and Lower Devonian rocks occupy narrow (80-100 m wide) shear zones in coastal exposures at School Brook and Cormorant Cliff coves at the northern extremity of the Cape George Peninsula (Fig. 2). The School Brook Cove and Cormorant Cliff Cove shear zones are bounded to the north and south by east-west trending faults which bring these rocks into contact with Devonian-Carboniferous conglomerates of the Horton Group (*sensu lato* in the designation of Keppie *et al.*, 1978). Bedding within the shear zones generally strikes to the north or northeast and dips to the west or northwest so that the oldest [Ordovician(?) and Silurian] rocks are exposed to the east.

Rocks assigned to the Ordovician by Boucot *et al.* (1974) consist of interbedded sandstone, shale and massive quartzite that are in faulted contact with younger successions at School Brook Cove. These rocks have yielded poorly preserved fossils identified as the Middle or Upper Ordovician brachiopods *Rhyncotrema* and *Rafinesquina* (Boucot *et al.*, 1974) but have also yielded conodonts identified as Lower Silurian (Keppie, 1978). They are locally hornfelsed by the intrusion of a medium- to coarse-grained hornblende monzonite (School Brook pluton) that does not cut younger rocks.

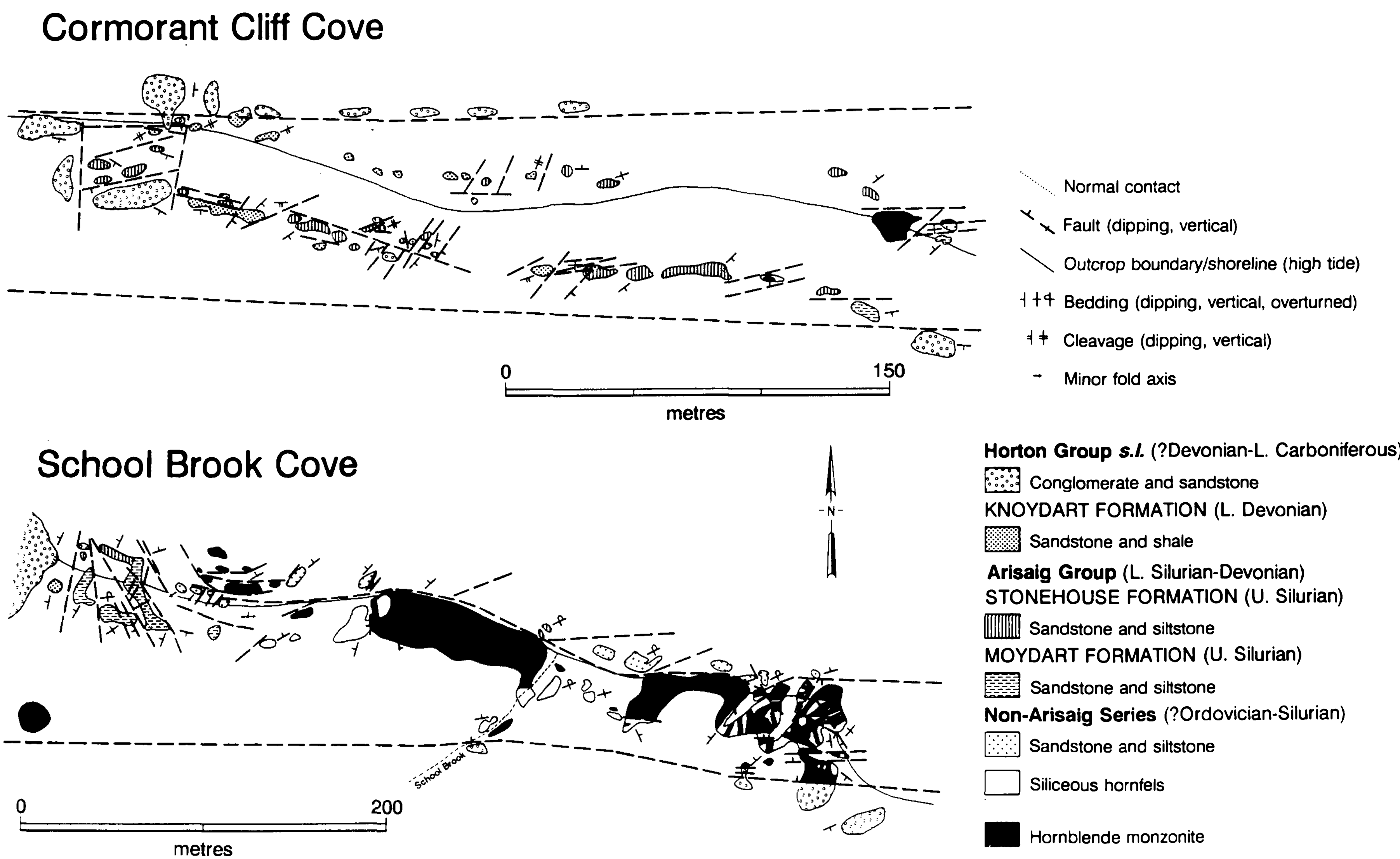

Fig. 2. Geological map of the Cormorant Cliff Cove and School Brook Cove shear zones (simplified after Boucot *et al.*, 1974).

Silurian rocks consisting of massive quartzite, *Skolithos*-bearing (worm tube) quartzite, red and grey to white cross-bedded sandstone, and grey-blue siltstone, occur in the northernmost portion of the fault zone exposed at School Brook Cove and cannot be directly correlated with any other Silurian sequence in Nova Scotia (Non-Arisaig Series of Boucot *et al.*, 1974). The upper and lower contacts of this succession are not exposed and the rocks lie in faulted contact with all other units in the area. Fossils of Silurian age consist chiefly of brachiopods, including dalmanellids and chonetids (Boucot *et al.*, 1974).

Other rocks within the shear zones are typical of the Silurian-Devonian Arisaig Group. A sequence of interbedded siltstone, sandstone, quartzite and mudstone that outcrop at School Brook and Cormorant Cliff coves has been correlated with the Upper Silurian Moydart Formation of the Arisaig Group (Boucot *et al.*, 1974). This correlation is based on lithologic similarities between the red beds at School Brook Cove and the "Red Band" stratigraphic marker unit at the top of the Moydart Formation. Red sandstone, algal nodules and red shaley sandstone are also present in both units. The upper contact of the Moydart Formation on Cape George is conformable with the Upper Silurian-Lower Devonian Stonehouse Formation. The lower contact is not exposed and all other contacts are faulted. Upper Silurian blue-green silty sandstones of the Stonehouse Formation are in faulted contact with sheared red to green sandstone and shale which were correlated with the Lower Devonian Knoydart Formation by Boucot *et al.* (1974) on the basis of lithological comparison with the type area near Arisaig.

The Middle to Upper Devonian McAras Brook Formation, located south of the Cape George Fault (Fig. 1), consists of a 190 m sequence of interbedded red to grey conglomerate, sandstone, shale and intervening basaltic flows. Middle Devonian spores have been found in grey shale at Ballantynes Cove allowing correlation with the McAras Brook Formation type section (Keppie *et al.*, 1978). At Ballantynes Cove (Barnhill, 1980; Bruck *et al.*, 1985), overturned beds of the McAras Brook Formation are structurally overlain by conglomerates of the Horton Group (*sensu lato*) along the north-dipping Cape George Fault. To the south, along the Greendale Fault, the McAras Brook Formation is in faulted contact with rocks of the Carboniferous Windsor Group. Five hundred metres south of Livingstone Cove, the formation rests with angular unconformity on the late Precambrian Georgeville Group. At Livingstone Cove, the McAras Brook Formation is again separated from the structurally overlying Horton Group (*sensu lato*) to the north by the Cape George Fault. The relatively small percentage of granitic pebbles in the conglomerates of the McAras Brook Formation has been used to distinguish them from conglomerates of the Horton Group (*sensu lato*) (Boucot *et al.*, 1974).

The "Pre-Wilkie Brook Succession" consists of sandstones and shales that outcrop to the south of the Greendale Fault (Fig. 1) and contain Upper Devonian spores (Benson, 1970; Keppie *et al.*, 1978). The base of this succession is not exposed. The upper contact is an angular unconformity with the Carboniferous Wilkie Brook Formation.

The Horton Group (*sensu lato* in the designation of Keppie *et al.*, 1978) on the Cape George Peninsula is a thick sedimentary sequence consisting predominantly of red polymictic conglomerate with minor sandstone and siltstone. The sequence occupies the entire northern portion of the peninsula (Fig. 1), except for the shear zones at School Brook and Cormorant Cliff coves, and exhibits normal graded bedding with pebbles and matrix becoming finer upward. The group structurally overlies the McAras Brook Formation to the south along the Cape George Fault and is in faulted contact with the Ordovician(?) to Devonian rocks exposed at School Brook and Cormorant Cliff coves, except at the western end of School Brook Cove (Fig. 2), where it rests with angular unconformity on the Devonian Knoydart Formation (Boucot *et al.*, 1974). Although a plant fossil (*Lepidodendropsis*) of probable Lower Carboniferous age was found in the basal conglomerate on the north coast of Cape George (W.H. Bell, in Boucot *et al.*, 1974), Keppie *et al.* (1978) favoured a Middle to Upper Devonian age for these conglomerates based on correlation with the "Pre-Wilkie Brook Succession" south of the Greendale Fault. No further constraints on the stratigraphic age of the group are possible.

The thickness of the Horton Group (*sensu lato*) is difficult to estimate due to structural complexities. In the northern portion of the Cape George Peninsula, Boucot *et al.* (1974) described a sequence comprising a basal conglomerate (150 m), a sandy conglomerate (910-1220 m) and a silty conglomerate (150-300 m). Clasts are angular to sub-angular and range in size from 1 cm to 1.5 m, suggesting that they were deposited in close proximity to their source. Deformed conglomerates of the Horton Group (*sensu lato*) occur adjacent to the Cape George Fault at Ballantynes Cove (Fig. 1) and are in faulted contact with less deformed Horton Group (*sensu lato*) to the north (Barnhill, 1980; Bruck *et al.*, 1985).

The Wilkie Brook Formation predominantly comprises red polymictic conglomerate which grades upward into an interbedded sequence of conglomerate, sandstone, siltstone, shale and limestone. The upper part of the formation consists mainly of conglomerate. Keppie *et al.* (1978) suggested a Late Tournaisian or Early Visean age for the formation based on an assemblage of spores collected on Cape George. The lower contact is an angular unconformity with the Upper Devonian "Pre-Wilkie Brook Succession" and possibly an unnamed rhyolite of pre-Silurian (?) age (Fig. 1). The formation is conformably overlain by the Marsh Cove Limestone which is 21.3 m thick and is correlated with the basal A1 limestone of the Late Visean to Early Namurian Windsor Group (Keppie *et al.*, 1978). The northern contact of the Marsh Cove Limestone is truncated by the Greendale Fault which brings it into contact with the McAras Brook Formation to the northwest.

STRUCTURAL GEOMETRY

Faults

The Cape George Peninsula is bounded by the NE-trending Hollow Fault to the northwest and by the subparallel Greendale Fault to the southeast (Fig. 1). The Hollow Fault is a major regional structure which approximately parallels the coast but curves westward inland to merge with the Cobequid-Chedabucto fault system (inset, Fig. 1) where it forms the southern boundary fault of the east-west Stellarton Graben. The fault intersects the shore at Malignant Cove and separates the late Precambrian and early Paleozoic rocks of the Antigonish Highlands from younger Silurian and Devonian-Carboniferous rocks to the north. Yeo and Gao Ruixing (1987) suggested that the Stellarton Graben developed as a result of the transfer of Late Carboniferous (Late Visean to Westphalian D) dextral strike-slip movement from the Hollow Fault to the Cobequid Fault via a step-over zone. The gently ENE-plunging striations and Reidel shear fracture arrays that these authors described are consistent with subhorizontal dextral slip on this segment of the Hollow Fault. Regionally, the fault is a major north-side-down Appalachian lineament and constitutes the northwestern boundary of a narrow zone within which second order structures and relatively intense deformation occurred in Late Paleozoic rocks.

The NE-trending Greendale Fault, which intersects the shore at Marsh Cove (Fig. 1), is marked by a prominent scarp that can be traced to within 120 m of the shoreline. The fault can also be traced to the southwest on radar lineament and vertical gradient magnetic maps where it merges with the Hollow Fault. In the study area, the Greendale Fault is separated from the Hollow Fault by about 4 km and constitutes the southeastern boundary of the zone of relatively intense Late Paleozoic deformation. The fault separates Late Precambrian rocks and the McAras Brook Formation to the northwest from predominantly Devonian to Carboniferous sedimentary strata to the southeast. At Ballantynes Cove, the Greendale Fault truncates the Cape George Fault as delineated by the vertical gradient magnetic anomaly between mafic volcanic rocks of the McAras Brook Formation and conglomerate of the Horton Group (*sensu lato*). Immediately south of the fault, at Marsh Cove, the Windsor Group (Marsh Cove Limestone) is strongly deformed. This deformation dies out rapidly to the south and is probably associated with movement along the fault. Hence the Greendale Fault is likely to have been active until at least post-Windsor time (Late Visean-Early Namurian). North of the fault the conglomerates and basalts of the McAras Brook Formation have been fractured and sheared. These rocks contain a brecciated zone and several NE-striking minor faults considered to be associated with the Greendale Fault. Slickensides on these minor faults pitch moderately to steeply southwest. These data, together with stratigraphic relations which place younger rocks to the south of the fault, indicate oblique-slip movement on the Greendale Fault with south-side-down and dextral components.

On a regional scale, geological maps and maps of radar lineaments and vertical gradient magnetic anomalies clearly show that the Hollow and Greendale faults merge with each other and the Cobequid-Chedabucto fault system to the southwest, and bound a zone of structures of similar scale and orientation as those bounded by the east-west shear zones at Cape George. Both faults are therefore considered to be part of a regional dextral strike-slip regime that was active from at least Late Visean to Westphalian D time, and associated with movement on the east-west Cobequid-Chedabucto fault system (Avalon-Meguma terrane boundary) to the south.

A series of generally east-west striking and steeply north-dipping shear zones occurs on the Cape George Peninsula. The three major shear zones exhibit both brittle and ductile deformation and include the Cape George Fault and the shear zones at School Brook and Cormorant Cliff coves. These east-west shear zones, and the deformation associated with them, are apparently confined between the Hollow and Greendale faults. Hence their origin and displacement is inferred to have been controlled by motion along the Hollow and Greendale faults which occurred in response to dextral movement on the Cobequid-Chedabucto fault system.

The Cape George Fault extends east-west from Ballantynes Cove to Livingstone Cove and truncates regional magnetic anomalies. For much of its length it coincides with the "Livingstone-Ballantynes Cove Fault" of Boucot *et al.* (1974). The fault is a brittle-ductile shear zone at Ballantynes Cove to the east, where it consists of several discrete north-dipping dislocation surfaces bounding mylonitic zones but comprises a single shear zone characterized by relatively ductile deformation at Livingstone Cove to the west.

North of the Cape George Fault, Horton Group (*sensu lato*) conglomerates are cut by numerous minor faults, but the amount and sense of displacement along these faults is difficult to determine due to the lack of stratigraphic markers. The steeply dipping School Brook Cove and Cormorant Cliff Cove shear zones at the northern end of the peninsula contain blocks of Ordovician(?), Silurian and Devonian rocks up to 17 m in width which define zones of mega-breccia that are fault-bounded to the north and south against Horton Group (*sensu lato*) conglomerate (Fig. 2).

Folds

Within the deformed conglomerate of the Horton Group (*sensu lato*) at Ballantynes Cove, opposing younging directions occur that are consistent with the presence of mesoscopic, SW-verging, asymmetric folds with axial surfaces approximately co-planar with the Cape George Fault (Barnhill, 1980). Immediately south of the Greendale Fault, at Marsh Cove, axes of minor folds within the Lower Carboniferous Windsor Group plunge moderately to the west-southwest. Megascopic folds in the adjacent Wilkie Brook Formation (Fig. 1) plunge gently east-northeast (Boucot *et al.*, 1974).

South of Ballantynes Cove (Fig. 1), opposing younging directions within the McAras Brook Formation on either side of a covered interval suggest the presence of a tight megascopic syncline with an overturned northern limb (Boucot *et al.*, 1974; Keppie *et al.*, 1978; Bruck *et al.*, 1985). The axial surface of this gently west-plunging structure dips steeply to the north and is subparallel to the Cape George Fault.

The attitude of Horton Group (*sensu lato*) conglomerates between the Cormorant Cliff Cove and School Brook Cove fault zones also suggests the presence of a westerly plunging syncline (Fig. 1). On the northern limb, beds are vertical or overturned to the south, whereas bedding on the southern limb dips 40 to 50° north (Boucot *et al.*, 1974). These conglomerates are, therefore, inferred to have been folded into a south-verging, asymmetric syncline.

Deformation associated with these folds dies out rapidly away from the faults, suggesting that the faults and folds are of similar age. A genetic link is also suggested by the component of southward vergence on both sets of structures (Nance, 1980).

Kinematic Analysis

In an attempt to understand the deformation responsible for the structural development of the Cape George Peninsula, this study includes a structural analysis of the major east-west trending shear zones and their associated tectonic fabrics. Ductile deformation and penetrative fabric development are intimately associated with these shear zones, outside which rocks are only mildly deformed.

Kinematic indicators are well developed within the east-west shear zones and include S-C fabrics, slickensides on major dislocation surfaces, and extensional fractures and veins (Fig. 3). C-fabrics are recognized as discrete dislocation surfaces that parallel the bounding walls of the shear zones. S-fabrics occur as a penetrative cleavage defined by the stretching and flattening of mineral grains in zones bounded by C-fabric planes (Fig. 3a). Slickensides on C-planes occur both as calcite lineations and as striations. Extensional fractures and veins are characterized by growth of vein material (usually calcite) inward from the bounding walls of the fracture. The orientation of these fabrics (Fig. 4) were measured at four key locations (see data collection sites, Fig. 1) where the major east-west shear zones of the Cape George Peninsula are well exposed and tectonic fabrics are well developed.

Cape George Fault

At Livingstone Cove (location L; Fig. 1), ductile stretching and flattening of pebbles within the polymictic conglomerates of the McAras Brook Formation define a locally intense, north-dipping planar fabric within the Cape George Fault. The character of deformation changes across the shear zone from ductile in the centre to brittle at the margins. In the intensely deformed central section of the shear zone, the stretched pebbles define a strong lineation. This section is about 50 m in width and outcrops on the shoreline approximately 15 m south of Livingstone Brook. Toward the shear zone margins, deformation is less intense and the stretched pebbles are contained in a cataclastite matrix which exhibits a crude planar fabric (Fig. 3b). As the intensity of deformation decreases, the long axes of stretched pebbles rotate progressively anticlockwise from nearly down-dip to gently NW-plunging orientations. These relationships and the north-westerly plunge of slickensides (Fig. 4a), are consistent with oblique slip on the Cape George Fault with dextral and reverse components.

At Ballantynes Cove (location B; Fig. 1), the Cape George Fault occurs as two steeply north-dipping shear zones which bound a deformed, polymictic conglomerate unit of probable Devonian-Carboniferous age. The steeply north-ward dipping conglomerate generally youngs to the south but shows reversals in younging direction consistent with the presence of mesoscopic, SW-verging, asymmetric folds, whose axial surfaces are approximately co-planar with the Cape George Fault (Barnhill, 1980). The southern boundary of this shear zone is defined by a tabular zone of sheared conglomerate, 10 to 20 cm in width, bounded by dislocation surfaces that strike east-west and dip steeply north. A steep cleavage strikes 10 to 20° anticlockwise of the dislocation surfaces within this tabular zone (Fig. 3c), and slickensides on parallel fault planes within adjacent basalt flows of the McAras Brook Formation pitch about 20° west. Extensional fractures and veins developed in pebbles of the deformed conglomerate are nearly vertical and strike northwest (Fig. 3d). The relative orientation of C- and S-fabrics, the moderate to gentle northwesterly plunge of slickensides on C-planes, and the orientation of extensional features in pebbles of the deformed conglomerate (Fig. 4b) are again consistent with dextral displacement on the Cape George Fault that incorporates a component of reverse dip-slip.

School Brook Cove shear zone

The shear zone at School Brook Cove (location S; Fig. 1) is at least 100 m wide, contains blocks of Ordovician(?) to Early Devonian rocks, and is bounded to the south by a steeply north-dipping east-west fault that separates Ordovician(?) strata of the shear zone (Fig. 2) from rocks of the Horton Group (*sensu lato*) to the south (Boucot *et al.*, 1974). The shear zone is characterized by deformation of Horton Group (*sensu lato*) conglomerate pebbles which become increasingly flattened and stretched (with a gently west-plunging elongation) northward toward the contact with the School Brook pluton. Major dislocation planes (C-fabric) within the shear zone dip steeply north and contain gently to moderately westward-plunging slickensides (Fig. 4c). The relative orientation of C-planes to the flattening (S-)fabric suggests dextral displacement and is consistent along the length of the southern boundary fault and on parallel faults within the shear zone. Extensional calcite veins adjacent to the southern boundary fault dip steeply southwest consistent with dextral strike slip.

Minor vertical fault planes within the School Brook Cove shear zone strike northeast and exhibit sub-horizontal slickensides indicating predominantly strike-slip motion.

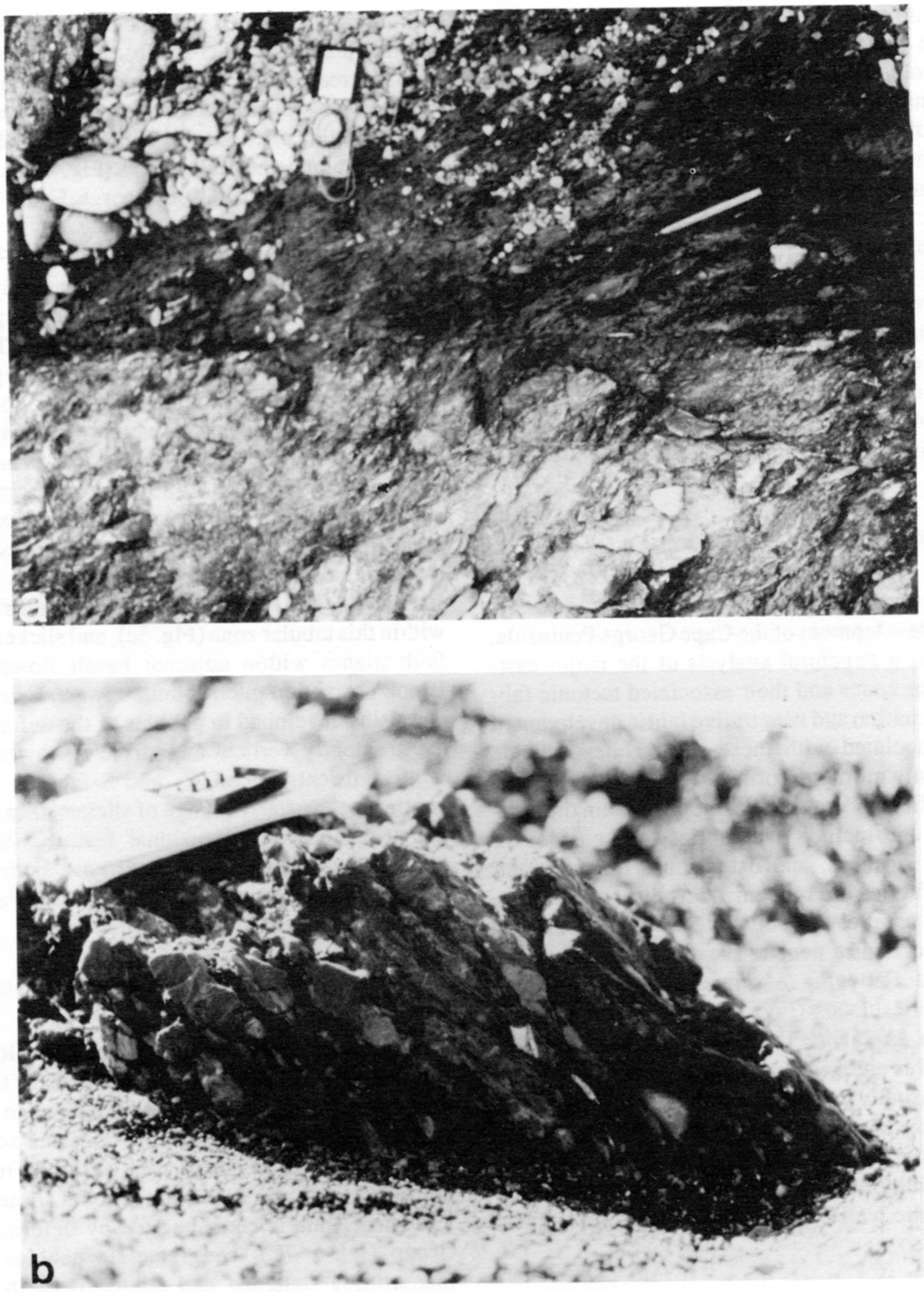

Fig. 3. (a) Down-dip view of E-W shear zone in Horton Group (*sensu lato*) conglomerates at Cormorant Cliff Cove showing development of S-fabric (parallel to pen) and C-fabric (parallel to shear-zone margins). North towards base of photo. (b) Crude planar fabric defined by stretched pebbles in the Cape George fault zone at Livingstone Cove. Viewed west along strike of the Cape George Fault.

Clockwise C- to S-fabric relationships indicate sinistral displacement on several of these faults (Fig. 3e), suggesting that they may be X-shears antithetic to the predominantly dextral School Brook Cove shear zone.

Cormorant Cliff Cove shear zone

The shear zone at Cormorant Cliff Cove can be mapped for over 200 m (Boucot *et al.*, 1974). The vertical northern boundary fault separates Horton Group (*sensu lato*) conglomerate to the north from blocks of Silurian and Devonian rocks within the fault zone (Fig. 2) and is marked by a 65 cm-wide interval of horizontally stretched conglomerate pebbles. The southern boundary of the shear zone is defined by an east-west fault which separates Horton Group (*sensu lato*) conglomerate to the south from Silurian rocks on the shore.

The mega-breccia between the two bounding faults contains several blocks of Horton Group (*sensu lato*) as well

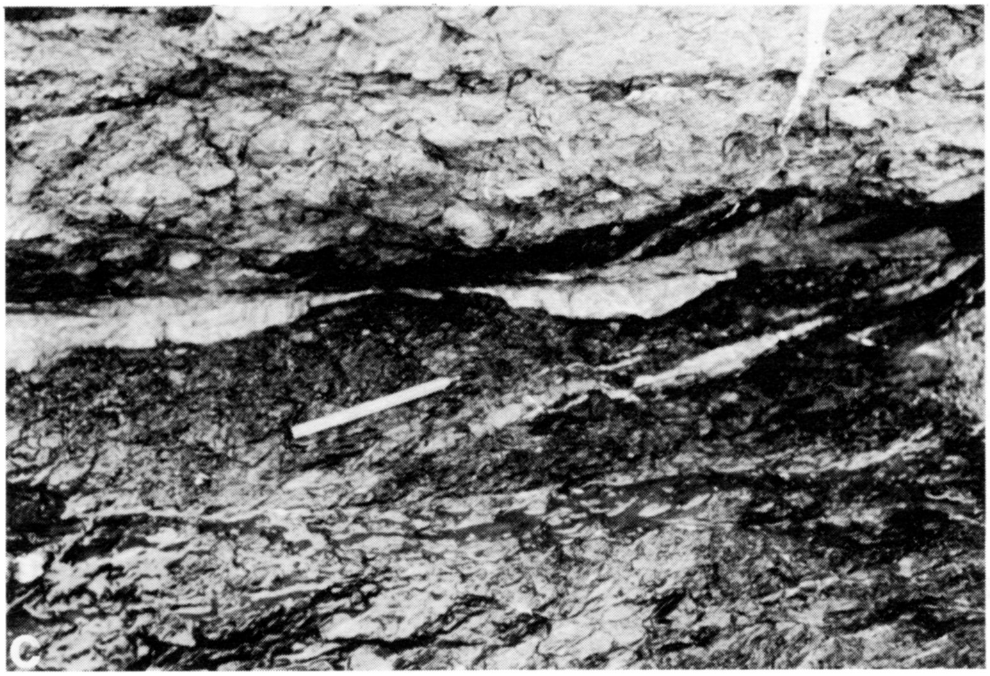

Fig. 3. (c) Down-dip view of the Cape George Fault at Ballantynes Cove showing S-fabric (parallel to pen) and C-fabric (parallel to shear-zone margins). Note dextral deflection of the calcite vein at top right. North towards top of photo. (d) Extensional fractures and veins in clasts of the McAras Brook Formation adjacent to the Cape George Fault at Ballantynes Cove. Strike of Cape George Fault parallel to the pen. North towards top of photo.

as minor Ordovician(?) quartzite, hornblende diorite, and the Silurian Moydart Formation. Deformation within these units varies from brittle to ductile shear (Fig. 3f), with intensity generally increasing northwards across the fault zone. Locally, east-west dislocation surfaces parallel to the major bounding faults separate zones of well-developed near-vertical cleavage striking east-northeast parallel to the flattening plane of pebbles in deformed Horton Group (*sensu lato*) conglomerate (Fig. 3g). These minor faults dip north but steepen northward and become steeply south-dipping in the northernmost exposed portion of the fault zone to form a configuration resembling a flower structure. The orientation of S-C fabrics (Fig. 4d) and stretched conglomerate pebbles are consistent with subhorizontal dextral displacement along the Cormorant Cliff Cove shear zone.

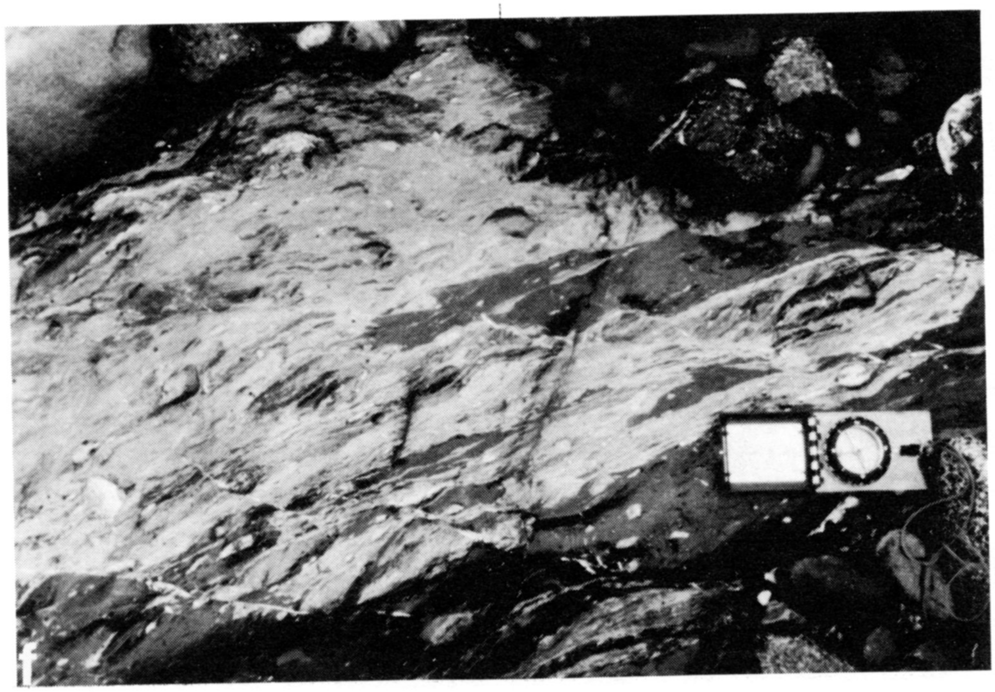

Fig. 3. (e) S-fabric (parallel to pen) and C-planes (parallel to shear-zone margins) indicating antithetic sinistral displacement in a minor X-shear oblique to (anticlockwise by 40°) and confined within the bounding faults of the School Brook Cove shear zone. North toward upper right-hand corner of photo. (f) Intense ductile deformation in Devonian Knoydart Formation at Cormorant Cliff Cove. Compass parallel to major E-W dislocation surfaces. North towards top of photo.

INTERPRETATION

East-west shear zones

The locally developed tectonic fabrics within and adjacent to the east-west shear zones of the Cape George Peninsula affected Devonian-Carboniferous strata and show relative orientations consistent with their development in a Late Paleozoic stress regime that induced dextral and subordinate reverse components of slip along these faults (Fig. 4). This is supported by S-C fabrics, and by the predominantly WNW-plunging orientation of slickensides, the NE- to ENE-strike of steeply dipping flattening (S-)fabrics, and the northwesterly strike of planar extensional features that are oriented normal to the flattening fabric (Fig. 4). Occasional sinistral shears, confined between and oblique to the east-west shear

Fig. 3. (g) Tectonic fabrics developed in the Cormorant Cliff Cove shear zone. S-fabric (parallel to pen) and C-fabric (parallel to spine of book) indicate dextral displacement along the major E-W dislocation surfaces. North towards top of photo.

zones, trend northeast and are interpreted as antithetic X-shears within the dextral strike-slip regime. In the absence of evidence of overprinting of older structures by younger ones, the consistency of the kinematic data suggests a single, if prolonged, period of dextral transpressive shear during the Late Paleozoic.

The Late Paleozoic tectonic history of Maritime Canada is dominated by regional dextral strike-slip activity along major lineaments associated with the latest accretionary events of the Appalachian orogen (e.g., Keppie, 1992). In Nova Scotia (Fig. 5), these lineaments are dominated by the Cobequid-Chedabucto fault system along which well-documented dextral strike-slip motion (e.g., Mawer and White, 1987) during the Late Carboniferous became increasingly transpressive as the fault system deviated from its east-west trace (e.g., Nance, 1987; Waldron *et al.*, 1989). Similar relationships exist on a much smaller scale along the east-west shear zones of the Cape George Peninsula (inset, Fig. 5) where associated megascopic folding, like that at Ballantynes Cove and the northern tip of the peninsula, is confined to regions where the curvature of individual fault traces relative to their recorded senses of shear is consistent with that of a restraining bend. If, as seems likely, dextral motion along these east-west shear zones coincided with Late Carboniferous movement on the NE-trending Hollow and Greendale faults, a significant component of reverse dip-slip displacement would be mandated on the latter structures. This, too, is consistent with the orientation of the Hollow and Greendale faults relative to the Cobequid-Chedabucto fault system. Striations and Reidel shear fracture arrays described by Yeo and Gao Ruixing (1987) document subhorizontal dextral strike slip on the Hollow Fault along the southern margin of the Stellarton Graben (SG, Fig. 5) where the fault trends east-northeast as it swings into the Cobequid-Chedabucto fault system. Further northeast, the striations retain their ENE-plunge despite an anticlockwise rotation in the fault trend of almost 40°. Curvature of the fault towards the northeast should consequently be accompanied by an increasing component of reverse dip slip. The east-west shear zones of the Cape George Peninsula which are confined by, and link, the Hollow and Greendale faults as their curvature increases are, therefore, considered to be second-order structures along which the increasingly reverse motion on the Hollow Fault was progressively transferred to the Greendale Fault by dextral strike-slip movement within a convergent step-over zone.

Hence, we interpret these east-west shear zones not as thrusts terminating dextral strike-slip motion on the Hollow Fault (Nance, 1980), but as dextral transfer faults synthetic to the Cobequid-Chedabucto fault system that developed in a strongly transpressive region between the Hollow and Greendale faults. The orientation of the transfer faults (Fig. 5) would be consistent with their development as Reidel R-shears within an east-west dextral shear regime (Bartlett *et al.*, 1981; Mandl, 1988), and is interpreted to reflect primary obliquity as we find no evidence to suggest that the angle between the shear zones and their bounding faults has been significantly modified by rotation during progressive dextral shear.

The Hollow and Greendale faults bring older rocks into contact with younger strata to the northwest and southeast, respectively, such that the northern Antigonish Highlands occupy the core of a "pop-up" structure between back-to-back reverse faults (Fig. 6). The Cape George Peninsula, which comprises a series of fault blocks which have been pushed up along high-angle synthetic faults as a result of dextral transpression, is thought to represent a transfer zone within this "pop-up" structure. The progressive steepening of the east-west faults toward the north, culminating in a reversal of dip at Cormorant Cliff Cove, suggests a positive flower structure configuration for the transfer zone. The absence of symmetry within the flower structure may reflect erosion of its northern half or initial development of the transfer zone as a southwest-directed half-flower structure.

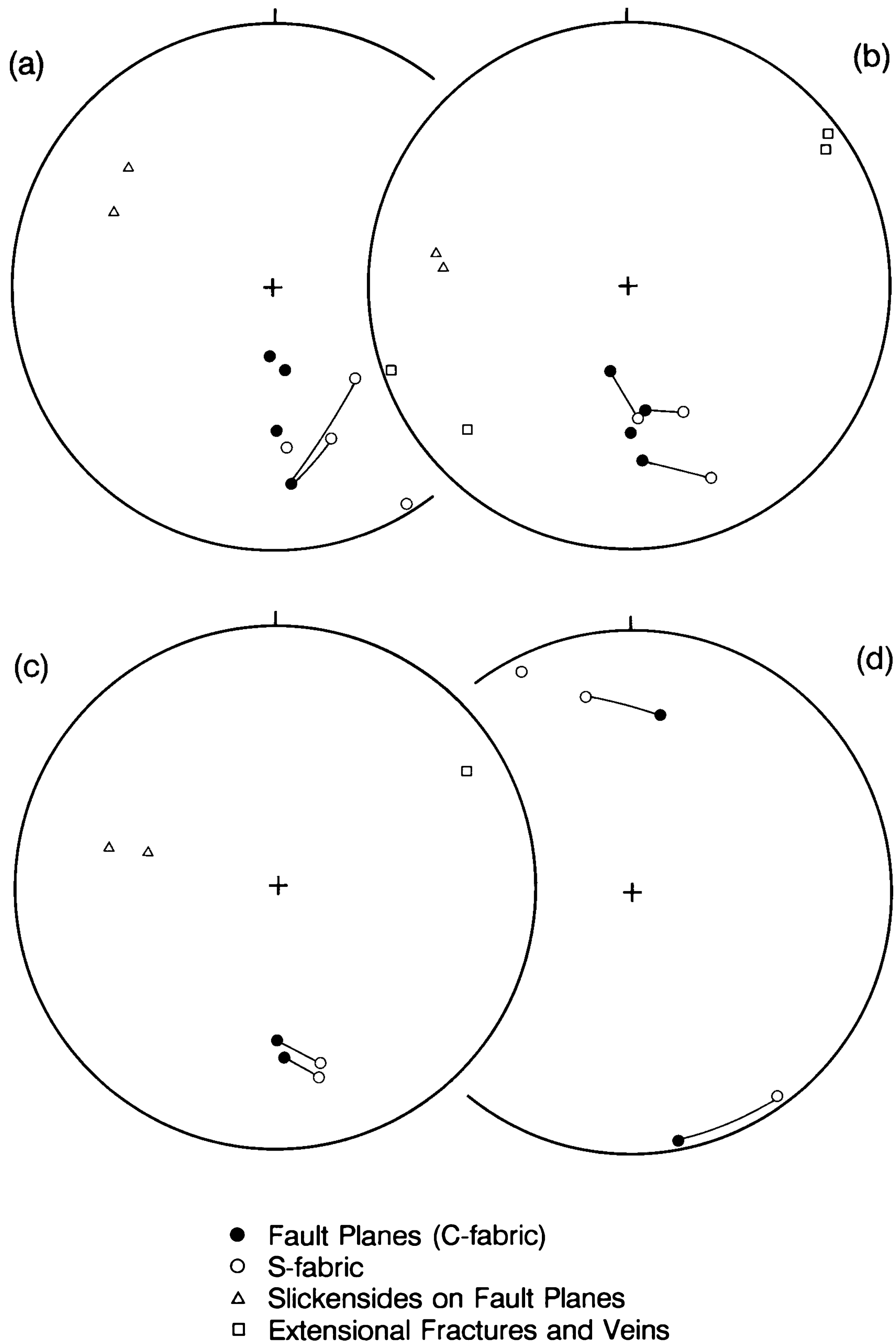

Fig. 4. Equal-area stereographic projections of kinematic indicators (tectonic fabrics) from east-west fault zones of the Cape George Peninsula. (a) Cape George Fault at Livingstone Cove, (b) Cape George Fault at Ballantynes Cove, (c) School Brook Cove shear zone, and (d) Cormorant Cliff Cove shear zone. Tie lines join measurements taken at the same outcrop.

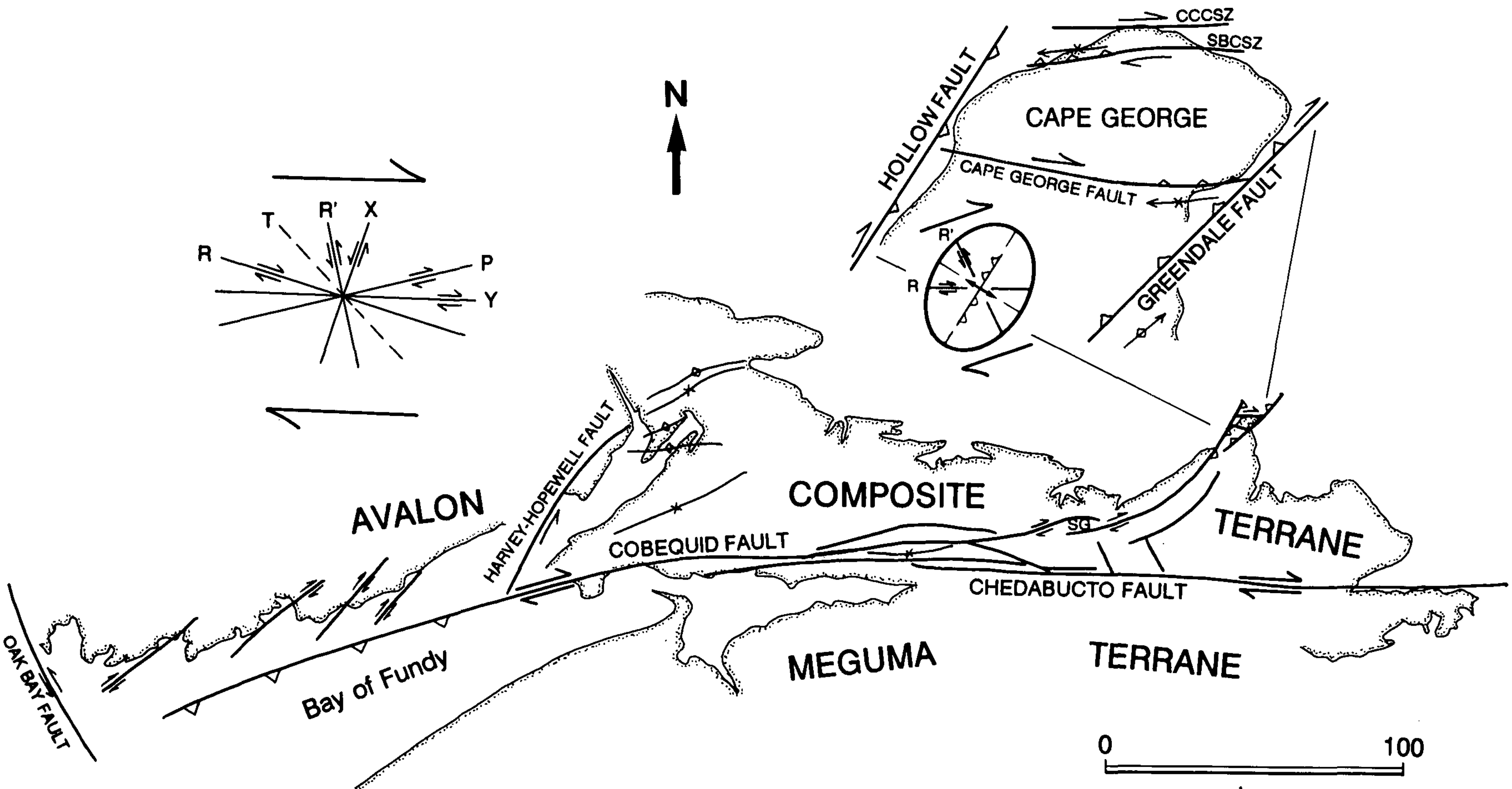

Fig. 5. Proposed regional Late Paleozoic kinematic geometry (modified after Nance, 1987) linking right-lateral, subhorizontal strike slip on the Cobequid-Chedabucto fault system with development of the Stellarton Graben (SG) and strongly convergent dextral shear and oblique-slip reverse faulting in the Antigonish Highlands. Shear fracture array for Y-, X- and P-shears, synthetic (R) and antithetic (R') Reidel shears, and tensional fractures (T), after Bartlett *et al.* (1981). Schematic strain ellipse indicating predicted Reidel shear and fold-thrust orientations after Harding (1974). CCCSZ - Cormorant Cliff Cove shear zone, SBCSZ - School Brook Cove shear zone. Fault pattern and fold axial traces simplified after Keppie *et al.* (1982).

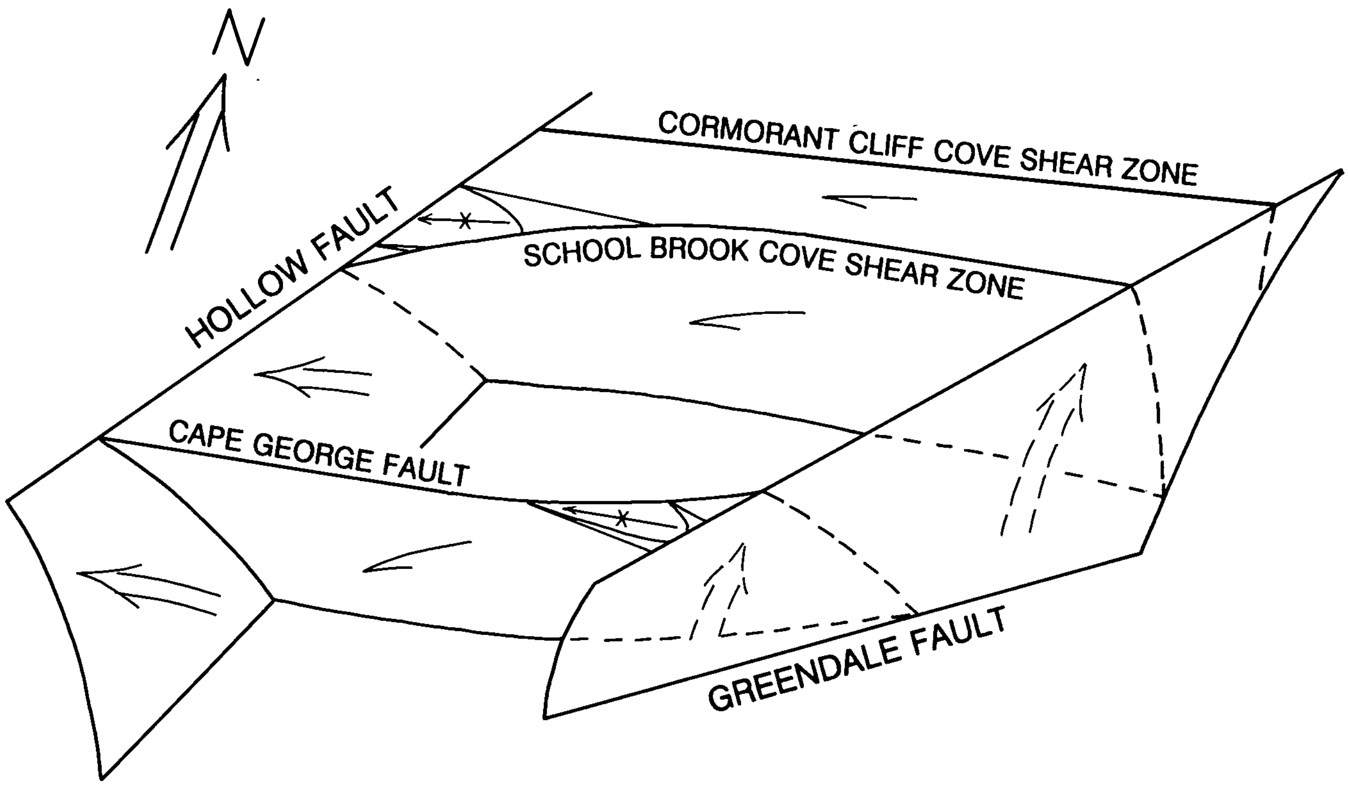

Fig. 6. Schematic three-dimensional interpretation of fault-fold relations on the Cape George Peninsula. Arrows indicate approximate vectors of movement.

Regional tectonic significance

The structural development of the Cape George Peninsula is consistent with regional tectonic syntheses which emphasize the importance of dextral strike-slip activity during waning stages of the development of the Appalachian orogen (e.g., Keppie, 1982a, 1992; Stockmal *et al.*, 1987). Coeval structures along the Cobequid-Chedabucto fault system are thought to reflect dextral movement of the Meguma terrane relative to the Avalon composite terrane during the Late Paleozoic (e.g., Keppie and Dallmeyer, 1987; Mawer and White, 1987; Waldron *et al.*, 1989; Keppie, 1992). On a regional scale (Fig. 5), structures are consistent with subhorizontal dextral movement where this terrane boundary trends east-west and with thrusting where it parallels the overall structural grain of the Appalachian orogen. In Maritime Canada, this is reflected in the localized development of transtensional and transpressional regimes in mainland Nova Scotia and in dextral transpression in westernmost Nova Scotia and the northeastern margin of the Bay of Fundy (Waldron *et al.*, 1989; Nance, 1987).

The development of the Stellarton Graben (SG, Fig. 5) has been attributed to transfer of Late Visean to Westphalian D dextral strike-slip movement from the Hollow Fault to the Cobequid Fault (Yeo and Gao Ruixing, 1987). However, as this study has shown, the same Hollow Fault becomes increasingly transpressive to the northeast as it curves northward into the Antigonish Highlands. In the Cobequid Highlands, Late Paleozoic rocks adjacent to the Cobequid and related faults also record deformation consistent with dextral displacement in which Late Visean-Early Namurian rocks are deformed into a series of NW-verging en echelon folds (Donohoe and Wallace, 1982; Miller *et al.*, 1989). Farther west, Visean to Namurian thrusting in the Cape Chignecto area resulted from dextral transpression along the Cobequid-Chedabucto fault system (Waldron *et al.*, 1989). In southern New Brunswick, the synchronous development of folds and thrusts strongly influenced Westphalian sedimentation and has been attributed to shortening across a major restraining bend in the Cobequid-Chedabucto fault system consistent with significant dextral displacement during the Late Carboniferous (Nance, 1987). Traced southwest beyond this bend, the Avalon-Meguma terrane boundary becomes listric and parallel to the Bay of Fundy. The penecontemporaneous development of these structural features suggests significant Late Paleozoic dextral translation and shortening between the Meguma and Avalon composite terranes.

Palinspastic reconstructions (e.g., Keppie, 1982a) suggest that the Cobequid-Chedabucto fault system has existed as a deflection in the generally NE-trending structural grain of the Appalachian orogen at least since the early Middle Devonian. The Late Paleozoic geometry and orientation of the Cobequid-Chedabucto fault system is thought to be the product of progressive collisional interaction between an irregular North American (Laurasian) cratonic margin and, successively, an Iapetan arc-trench complex and the North African continental margin of Gondwanaland (e.g., Stockmal *et al.*, 1987; Gibling *et al.*, 1992).

CONCLUSIONS

Kinematic indicators genetically related to east-west shear zones on the Cape George Peninsula are consistent with oblique slip involving components of dextral and subordinate reverse dip-slip movement. The shear zones are interpreted as synthetic transfer faults that developed during Carboniferous (Late Visean to Late Westphalian) dextral transpression between the NE-trending Hollow and Greendale faults of the Antigonish Highlands; a shear regime in turn linked to post-accretionary dextral movement between the Meguma and Avalon composite terranes along the east-west Cobequid-Chedabucto fault zone. Hence, the Cape George shear zones provide examples of local structural complexities that cannot be viewed in isolation since they reflect tectonic processes on a regional scale.

Coeval structures along the Cobequid-Chedabucto fault system are consistent with regional subhorizontal dextral strike-slip (e.g., Cobequid Highlands) and the local development of transtensional basins (e.g., Stellarton Graben), and transpressive deformation (e.g., Cape Chignecto, southern New Brunswick). This heterogeneity of deformational styles suggests that local stress regimes induced by dextral motion along regional faults were strongly influenced by local variations in fault geometry.

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