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Introduction

The St.John-St.George area extends from Loch Lomond on the east to Pasamaquoddy Bay on the west, a distance of about 100 km, and from the Bay of Fundy on the south to the area of South Oromocto Lake on the north, a distance of about 30 km. The terrane is moderately rugged, ranging from sea level on the Bay of Fundy to 300 m in the Nerepis Hills. Sea cliffs up to 100 m high fringe considerable parts of the coast, and cliffs up to 30 m high are quite common inland. The amount of bedrock exposed generally decreases with distance from the Bay, and is estimated to form 2 to 10 percent of the surface in most regions. Much of the rest of the surface consists of bouldery till derived from the west or northwest and stratified outwash or morainal deposits. Some glacio-marine deposits occur along the Bay of Fundy. The terrane is mainly wooded, with significant areas clear-cut during pulpwood harvesting in the last decade. Access is generally easy via secondary roads, woods roads and ATV tracks radiating from major provincial highways, but some areas around Loch Alva and the Musquash reservoirs require use of a boat and long walks through dense bush.

The field-work reported here examined all outcrops noted by previous workers, mainly along roads, trails and streams, and discovered many previously unmapped outcrops. However no effort was made to systematically traverse heavily wooded areas, except where aerial photographs indicated probable outcrop. Attention was directed toward revision of stratigraphy of late Precambrian igneous and metamorphic rocks and determination of structural relations, as well as chemical and isotopic characterisation of these rocks. The net result of this work was the remapping of NTS sheets 21G/1 (Musquash), 2 (Saint George), 8 (Saint John) and 21H/4 (Cape Spencer) and 5 (Loch Lomond). The geology of 21G/7 (McDougall Lake) is compiled from recent work by McLeod and Gardiner (1987, manuscript map).

Description of units

The stratigraphy of the mapped area has been discussed by numerous authours (Helmsteadt, 1968; Garnett, 1973; Rast et al., 1976; Wardle, 1977: Donohoe, 1978; Ruitenberg et al., 1979; Currie et al., 1981; Currie and Nance, 1983; Currie, 1984, 1986, 1988; McCutcheon and Ruitenberg, 1987; Tanoli, 1987). The oldest rocks form a narrow rib of mesocratic, migmatitic quartz-plagioclase-hornblende+/-biotite gneiss (Brookville gneiss, unit A_B on Fig.2) locally containing schlieren, patches and nebulous enclaves of biotite granite gneiss, unfoliated muscovite-tourmaline pegmatites, and relics of mafic dykes (amphibolite boudins). Major ductile shears (blastomylonites) mark the edges of the gneiss against the Green Head Group. These zones contain foliated marble dykes, commonly following mafic dykes, thought to indicate that the Brookville gneiss was diapirically emplaced into its surroundings as a hot plastic solid (Currie et al., 1981). Diapirism, with attendant high temperature deformation and emplacement of a mafic dyke swarm, probably occurred about 780 Ma, and affected rocks 1100-1200 Ma, as indicated by U-Pb zircon ages (Olszewski and Gaudette, 1982).

The Green Head Group (unit M_{G}) consists of dominant buff to grey, marble, with lesser amounts of lilac to pale grey, fine-grained quartzite and minor pelitic schist. Much of the Green Head Group lies at chlorite grade, but along the contact with the Brookville gneiss the rocks are locally at sillimanite grade (Wardle, 1977). Small enclaves of the Green Head Group are almost undeformed and contain well preserved stromatolites. Much of the unit has been intensely deformed, and the strong foliation is almost entirely of tectonic origin (Nance, 1982). Because of large scale internal flowage, no reliable internal stratigraphy for the Green Head Group is known. The depositional age also remains uncertain. Hofmann (1974) estimated 1000-1500 Ma on the basis of the stromatolites.

Turbiditic siltstones and debris flows of the Martinon Formation (unit H_{M}) rest unconformably on the Green Head Group west of Grand Bay. The Martinon Formation, which contains a significant component of basalt sills and flows, occurs mainly as a cuspate synformal enclave between large plutons for one of which Olszewski et al., (1980) reported an age of 615 Ma by Rb-Sr isochron. The age of the Martinon Fm. remains uncertain. S.R. McCutcheon (personal communication, 1988) pointed out that the lithology and stratigraphy resemble those of the Burin Group of

Newfoundland which has been dated at 762 Ma (Krogh et al., 1988).

The calc-alkaline, arc-related (McCutcheon in Ruitenberg et al., 1979) Coldbrook Group (unit H_c) consists of abundant grey-green intermediate, commonly fragmental volcanic rocks, including lahars and ignimbrites, subordinate basaltic flows, and minor sedimentary rocks, mainly rhythmically banded siltstones, with minor conglomerate and sandstone. I have nowhere observed an untectonised contact between Coldbrook Group and older rocks, but numerous dykes identical to grey green Coldbrook rhyolites cut the Brookville gneiss and Green Head Group, and xenoliths of both units occur within the Coldbrook near Upper Golden Grove. The internal stratigraphy of the Coldbrook Group remains uncertain due to lack of reliable markers and structural complexity. The general succession appears to be from basal basaltic rocks, through fragmental intermadiate rocks, to capping salic tuffs and sediments. The Coldbrook Group is pervasively altered with chlorite and epidote, and locally shows prehnite-pumpellyite metamorphic assemblages. The Coldbrook Group has proved difficult to date radiometrically. Stukas (1978) reported ages for volcanic rocks south of the Long Reach of 630-640 Ma by $^{40}A/^{39}A$, but it is uncertain that this age is either reliable or dates Coldbrook.

A suite of elongate dioritic to granodioritic I-type plutons (Golden Grove suite, unit H_g, Hayes and Howell, 1937) may be cogenetic with the Coldbrook Group, although the two units are not seen in close proximity except across faults. Golden Grove plutons typically exhibit cognate enclaves of acid and mafic rocks varying from net veining and agmatitic texture to spectacular mixing textures. Watters (1987) reported a preliminary Pb-U age on zircon of 625+/-15 Ma for the pluton at Cape Spenser. Rocks of the Golden Grove suite also exhibit the pervasive epidote-chlorite alteration typical of Coldbrook.

The youngest Precambrian rocks in southern New Brunswick comprise a bimodal sheeted dyke complex (Kingston complex, unit E_{K}), high level granitoid plutons (unit E_{G}), and a bimodal volcanic-red bed suite (unit E_{D}). The Kingston complex, with a strike length of more than 100 km and a width of 3 to 6 km, consists mainly of alternating salic and mafic dykes The central part of the complex is at greenschist grade (Leger, 1986) but the grade declines toward the margins, which are marked by major mylonite zones southwest of Loch Alva. Relict igneous textures ranging from phenocrysts, glomeroporphyritic texture, internal contacts and chilled contacts persist through much of the complex. In general the dykes vary from 1 to 5 m in width, rarely reaching 50 m. Chemically, the mafic parts of the Kingston complex form tholeiites of within-plate affinities, which show distinct resemblance to the older Coldbrook basalts (low U, Ti). Radiometric dating of the Kingston complex is in progress, but fossiliferous middle Cambrian strata rest unconformably upon it at the head of Beaver Harbour.

Leucocratic, equigranular red granodiorite to monzogranite bodies (unit E_G) characterized by strong radiometric Th signature (Shives, 1986) form lenticles within the Kingston complex and equant plutons outside it. Two of these bodies gave Pb-U zircon ages of 565+/-8 Ma (Currie, 1987, 1988). Typically the plutons exhibit a massive medium-grained granoblastic texture, and strong red discoloration, but marginal phases may be porphyritic, and these plutons grade continuously both to salic parts of the Kingston complex and to Eocambrian rhyolite. Chemical data on these plutons (for example Ta-Th-Hf ratios and Sr isotope ratios) imply that both plutons and the salic parts of the Kingston complex are crustal melts.

Red tuffaceous siltstone and conglomerate associated with basalt and rhyolite porphyry flows occur along and north of the Kingston complex and along the Fundy coast. The basal unit is a characteristic pink to greenish quartz-feldspar porphyry (unit E_r) which passes continuously into rocks of plutonic aspect and into ignimbritic to tuffaceous material with well preserved fiamme as well as various types of igneous breccia. The basalts, (unit E_b) which chemically resemble the Coldbrook Group, but show some transition toward within-plate chemistry, locally appear almost totally unaltered with preserved open vesicles and delicate igneous texture. The upper sedimentary section contains blood red tuffs with feldspar crystal debris, conglomerate of porphyry cobbles in a red to orange sandy matrix, and dominant red, cross-bedded lithic sandstone. These strata underlie the Cambrian Saint John Group with only slight angular discordance, suggesting the Eocambrian rocks and the basal Cambrian Ratcliffe Brook Formation of the Saint John Group may form a single stratigraphic unit distinct from the rest of the group.

Two types of Lower Cambrian to Lower Ordovician strata (unit C_S) occur. The Saint John Group (excluding the Ratcliffe Brook Fm.), a transgressive barrier-bar complex of sandstone and siltstone (Tanoli, 1987) lies unconformably upon the Coldbrook Group. It now appears mainly in fault slices. Characteristic units include, in ascending order, the Glen Falls Formation, a quartz pebble conglomerate with distinctive tourmaline-rich horizon, the Hanford Brook Formation, a dark grey green siltstone characterised by lenticular small black phosphatic nodules, Forest Hills and Kings Square Formations of grey fine-grained sandstones, commonly ripple marked, and the Silver Falls and Reversing Falls formations of black Shale.

At the head of Beaver Harbour a sequence of ignimbrite, vesicular basalt, lapilli tuff, tuffaceous siltstone and calcareous siltstone capped by red siltstone with volcanic cobbles rests unconformably on the Kingston complex and an Eocanbrian (?) granite. The lapilli tuff yielded middle Cambrian (P.benneti zone) fossils (Helmsteadt, 1968). Thin tuffaceous beds in the Saint John Group may be equivalent to this volcanic sequence.

Silurian to Devonian sedimentary and volcanic strata fringe the northwestern margin of the Precambrian rocks. Stratigraphy and nomenclature of these strata remain unresolved. McCutcheon and Boucot (1984) considered basalt, tuff and siltstone of the Llandovery Long Reach Fm. to be conformably overlain by siltstone of the Pridolian Jones Creek Fm. Currie (1987) found basalt and siltstone interbedded northwest of Grand Bay, suggesting more complex relations than those envisaged by McCutcheon and Boucot (1984), perhaps similar to the shallow marine-littoral, west-facing sections described by Donohoe (1978) and van Wagoner and Faye (1988) where sedimentary and volcanic rocks are interbedded throughout the section. The map therefore distinguishes only the general categories of volcanic-dominated (unit S[illegible]) and sediment-dominated (S_s). Unconformity between Silurian and Precambrian rocks has not been directly observed, but abundance of dykes in the Precambrian granites and granitic cobbles in the Silurian volcanics prove a hidden unconformity.

The "Saint George batholith" comprises five plutons of Silurian to Devonian age. High level alkaline to peralkaline granite (unit S_A) occurs in a linear belt which is interrupted by the Mt. Douglas pluton. The Jake Lee Mountain and Welsford complexes comprise high level miarolitic arfvedsonite-aegirine granite, reddish porphyries of various types, and a marginal mafic dyke suite which looks very fresh, but does not intrude younger members of the batholith. Volcanic strata correlative to the granite form part of the Pridolian Jones Creek Formation (Payette and Martin, 1987). The Bocabec complex (map unit D_{sb}) comprises sheets of gabbro grading to granodiorite and has yielded a Rb-Sr isochron age of 403 Ma (Fyfe et al., 1981). The Lake Utopia and Magaguadavic (395 Ma, Bevier, 1988) plutons consist of coarse equigranular biotite granite, the former cut by distinctive thin, purplish tuffisite veinlets. Late Devonian (367 Ma Bevier, 1988) coarse-grained, rapakivi to megacrystic biotite granite of the Mount Douglas pluton (map unit D_{smd}) cuts all older phases. The Mount Douglas pluton intruded both Silurian strata and Precambrian granite on its south side. Gravity modelling by Thomas and Willis (in press) suggests that the Bocabec complex is a thin sill, not more than a few hundred m thick, whereas the granitic rocks of the Magaguadavic, Lake Utopia, and Mt. Douglas plutons form a sheet some 6 km thick overlying Paleozoic strata and possibly Precambrian basement. The lack of minor intrusions around the south side of the Saint George batholith is striking. Only the Eagle Lake stock (Ruitenberg, 1969) may be correlative.

Carboniferous strata northwest of the Kingston complex comprise little deformed red sandstone and conglomerate of the Kennebecasis, Perry and Beaver Harbour formations (units DC_C) which are locally derived clastic sequences deposited in fault troughs. The lower parts of these formations are Late Devonian in age (Hayes and Howell, 1937; Alcock and Perry, 1960), while the upper parts may be as young as Westphalian (Currie, 1984). The Blacks Harbour member of the Perry Fm., as defined by Schluger (1973) consists of deformed red siltstone-sandstone sequences with abundant caliche horizons and coarse conglomerate intervals which occur in several fault troughs southeast of the Mascarene Group. Alcock and Perry (1960) considered the Perry Formation to be little deformed and to contain debris of Devonian granites. The beds in question obey neither criterion, do not correlate well with the rest of the Perry Fm., and may be significantly older, possibly lower Devonian to upper Silurian in age and equivalent to part of the upper Mascarene Group. The rocks are shown separately on the map under the name Blacks Harbour beds at the suggestion of N. Rast (personal communication).

Southeast of the Kingston complex, the Mispec Group (in the sense of Currie and Nance, 1983) represents an alluvial fan complex fed from the southeast (unit C_M). The lower (proximal) Balls Lake formation, resting unconformably on Coldbrook and Saint John Groups and Golden Grove suite, consists of red siltstone with conglomerate lenses, and basal caliche-rich layers with a local basal, black stromatolitic limestone. The upper (distal) Lancaster Formation consists of pale grey lithic arenite with quartz pebble beds and thin black, plant-bearing, siltstone layers. The Mispec Group is mainly of Westphalian age, although the range in age may be from Visean to Stephanian (Currie and Nance, 1983).

Chocolate coloured conglomerate and red siltstone of the Triassic Lepreau Formation (unit T_L) occur in several small, fault bounded troughs along the Bay of Fundy. These rocks are essentially undeformed except for normal faulting, and, unlike Carboniferous strata, do not show penetrative cleavage. A large thickness of Triassic rocks has been detected by oil exploration just off-shore in the Bay of Fundy.

Structure of the Saint John-Saint George area

Regionally developed, systematic folding is difficult to detect in the Saint John area. Pre-Coldbrook folding of the Brookville gneiss and Green Head Group cannot reliably be distinguished from younger deformation (Nance, 1982), although relations between Brookville gneiss and Green Head Group prove at least some deformation about 780 Ma. Late Precambrian folding of the Coldbrook Group and older rocks about 600 Ma is suggested where the Martinon Formation occurs as hornfelsed and migmatised synclinal keels between dated plutons, and where cleaved and mildly metamorphosed Coldbrook is juxtaposed against much less deformed and altered Eocambrian strata. Cobbles of deformed and altered Coldbrook Group and Golden Grove plutons occur in basal Cambrian beds at Baxter's Mountain.

Traditionally most folding was assigned to the Ordovician Taconian and Siluro-Devonian Acadian orogenies (Helmsteadt, 1968; Garnett, 1973; Wardle, 1977; Donohoe, 1978; Ruitenberg et al., 1979) although the evidence was at best circumstantial (see

Wardle (1977) for a careful discussion). Most workers now assign a Carboniferous age to strong folding and thrusting along the Bay of Fundy (Rast and Grant 1974; Rast et al. 1978; Currie and Nance, 1983; Parker, 1984; Nance and Warner, 1986; Caudill and Nance, 1986; Watters, 1987). Major folding of the Saint John Group resembles folds in nearby Carboniferous rocks in style and orientation (Currie, 1984). Minor folds in fault slivers of the Saint John Group appear to be related to faults (Wardle, 1977) known to exhibit Carboniferous movement.

Donohoe (1978) described polyphase Acadian folds and cleavage in the Saint George area, but noted that the Silurian section has a consistent northwest facing direction. Folding must therefore be local, presumably fault-related deformation, rather than large scale systematic folding. Penetrative cleavage of several ages occurs across the belt, but the trends of these cleavages are diverse and commonly related to faulting, rather than folding. In many cases the cleavage is demonstrably of Carboniferous or younger age, for example where it cuts Carboniferous rocks. In some cases a Precambrian age can be demonstrated, for example where uncleaved Cambrian rocks sit unconformably on the Kingston complex.

Numerous northeast, north and northwest-trending faults cut the terrane. Indeed the whole region between the Long Reach and the Bay of Fundy forms a high strain zone. Most faults belong to one of four groups, namely (a) northeast-trending, steeply-dipping mylonite zones, (b) northeast-trending steeply-dipping brittle faults, (c) north to northwest trending, steeply-dipping brittle faults, (d) northeast-trending, gently-dipping brittle-ductile faults.

(a) Northeast-trending mylonite zones fringe both sides of the Kingston complex from Beaver Harbour to Loch Alva. Mylonitization is intense in granitoid rocks but weak or absent in mafic dykes of the complex, which locally cut the mylonite at a high angle. The zones nowhere cut Phanerozoic strata and a sliver of Silurian unmylonitized fossiliferous siltstone has been downdropped into mylonitic granite on New River. Greenschist grade metamorphism affects dykes, mylonites and granites, but not overlying Cambrian strata, suggesting mylonitization by late Precambrian movement. These mylonite zones end abruptly at Loch Alva, but a mylonite zone further to the north near the upper New River cuts the Siurian Jake Lee Mountain complex. Most kinematic indicators suggest dextral motion (Leger, 1986) with a very consistent, northeast trending, steeply plunging lineation, but small scale sinistral indicators occur locally within the Kingston complex. Plutons of identical age and petrography occur on opposite sides of the zones, which appear to have dissected a magmatic suite, rather than juxtaposing unrelated suites. Most movement on these zones is probably of latest Precambrian age, but reactivation took place in Silurian or more recent time, possibly associated with emplacement of the Saint George batholith.

(b) Steeply-dipping northeast-trending brittle faults tend to follow older mylonite zones, but locally cut them at a low angle.

East of Loch Alva where the mylonite zones are absent or inconspicuous, faults form anastamosing breccia zones following the margins of the Kingston complex, and including out-of-sequence fault blocks. In some cases latest motion on these faults can be dated by emplacement of undeformed igneous or sedimentary rocks across them. These data suggest a range of movement ages from early Silurian to Mississippian. Geophysical modelling suggests significant high angle displacement on some of these faults (Thomas and Willis, in press; Spector and Pichette, 1980). A northwest side down motion totalling nearly 11 km is deduced beneath the Mt. Douglas pluton. Further south Helmsteadt (1968) and Garnett (1973) deduced only small displacements of a few tens of meters in Phanerozoic time, producing small grabens. To the southeast Gupta (1975) deduced a km scale down-drop of the southeastern side on the Green Head-Coldbrook boundary. This pattern suggests systematic uplift of the exposed Avalonian rocks relative to their surroundings. The close geometric relation of these brittle faults to older ductile zones suggest reactivation of old zones of weakness.

(c) Little detailed work work has been done on the north to northwest-trending features because of poor exposure. Small scale exposed faults northwest of Grand Bay show mainly normal movement with alternating sinistral and dextral components, and brittle to brittle ductile deformation along steeply dipping planes. The Grand Bay-Welsford, Loch Alva and Lepreau River lineaments form parallel but much larger features. Age(s) of motion remain unknown, since no stratigraphic relations have been found involving these faults, but at the largest scale, the effect has been to expose deeper seated rocks to the west. Possibly ages of motion may be similar to those for the northeast-trending faults, that is ranging from late Precambrian to Devonian. Orientation of lineaments relative to the northeast trending structures suggests a Riedel shear pattern, which would imply east-west compression and sinistral motion of northwest-trending faults.

(d) Moderate to low angle faults occur along the Bay of Fundy. (Rast and Grant, 1974; Rast et al., 1978; Currie and Nance, 1983; Parker, 1984; Nance and Warner, 1986; Watters, 1987) which have imbricated slices toward the west, although backthrusts are common. Along the Bay of Fundy, older mylonite zones have been partially overprinted by Carboniferous deformation (Rast and Dickson, 1982), but this effect extends only a few kilometers inland. The style of deformation ranges from brittle to ductile, and chloritoid-grade metamorphism occurs in narrow belts of Pennsylvanian rocks within the zones (Currie, 1986).

Economic geology

Gold occurs in shear zones along the Bay of Fundy, and a producing mine lies just north of Cape Spenser. Mineralization is associated with silicified mylonite zones which may contain either disseminated secondary quartz or large lenticles of massive quartz (Watters, 1987). Mineralisation appears most promising in foot-wall zones beneath thrust granite allochthons, but the role of lithologies is at present not well understood.

The favourable zone of Carboniferous mylonites extends more than 50 km from the neighbourhood of Saint Martins almost to Point Lepreau.

Somewhat similar environments in older steep mylonite zones along the Kingston complex have also been prospected, but with indecisive results.

Cu mineralisation occurs along Highway 7 just south of Cunningham Creek associated with a melagabbro of probable Eocambrian age. A similar pluton touched by Highway 1 (Duck Lake pluton) gives anomalous values in Ni and platinum group elements.

The Mount Douglas pluton of the Saint George batholith and its aureole host a number of prospects, mainly for W, Mo, Sn and Cu but with local Bi and Co (McCutcheon and Ruitenberg, 1987). Within the pluton mineralisation is of greisen type in veins of highly fractured quartz, white mica, topaz, fluorite and epidote associated with late altered porphyry phases of the pluton. Arsenopyrite, wolframite, molybdenite, pyrite, pyrrhotite, chalcopyrite, cassiterite and galena occur along fractures. Similar mineralisation outside the pluton occurs in skarn-type masses rich in garnet and tourmaline.

Stringers and pods of siderite-quartz with sphalerite, argentiferous galena, chalcopyrite and tetrahedrite occur with aplitic rocks of the Welsford pluton near McKeel Lake and Johnson Croft. Both occurrences have been trenched and drilled (McCutcheon and Ruitenberg, 1987). The Eagle Lake stock is also associated with Cu-Mo mineralisation (Ruitenberg, 1969).

The Long Reach mafic volcanics and correlative rocks further to the southwest locally contain disseminated chalcopyrite on fracture surfaces, particularly where quartz veins are abundant, but none of these occurrences appear of major importance.

Ornamental and dimension stone has been quarried from plutons of the Saint George betholith for many years. Lancaster Fm. rocks near Reserve Lake were drilled for coal many years ago, but with discouraging results (Alcock and Perry, 1960).

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