Ophiolitic mélange and its significance in the Fleur de Lys Supergroup, northern Appalachians

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Received 20 December 1976
Revision accepted for publication 2 February 1977

Ophiolitic mélange consists of a chaotic mixture of sedimentary rocks and igneous rocks derived from the ophiolite suite of rock units. Its formation involves surficial mass wastage, gravity sliding, and tectonism at consuming plate boundaries. Most worldwide examples relate to ophiolite obduction and the destruction of stable continental margins.

The Fleur de Lys Supergroup of the northern Appalachians consists of polydeformed and metamorphosed, mainly clastic sedimentary rocks that accumulated at the Hadrynian to early Paleozoic stable continental margin of eastern North America. Greenschists at or near the top of the succession in the east (Birchy Complex) contain zones of typical ophiolitic mélange. These contain large blocks of serpentinized ultramafic rocks, actinolite–fuchsite alterations of smaller ultramafic blocks, altered gabbro, a variety of clastic sedimentary blocks, and marble. All of the rocks are multideformed and metamorphosed so that the mélange was subjected to the full range of Fleur de Lys deformations.

The presence of polydeformed and metamorphosed ophiolitic mélange in the Fleur de Lys Supergroup implies an early disruption or imbrication of its rock units. This disruption and mélange formation are interpreted to be related to transport of ophiolite complexes such as the Bay of Islands Complex across an initially undisturbed continental rise prism, the Fleur de Lys Supergroup. Later polyphase deformation and metamorphism of the Fleur de Lys Supergroup are possible results of continued structural submergence and telescoping of the continental margin beneath a thick cover of transported ophiolite rock units.

Un mélange ophiolitique consiste en un amas chaotique de roches sédimentaires et ignées qui dérivent d'une suite ophiolitique d'unités lithologiques. Sa formation est attribuable à des mouvements de masse superficiels, à des glissements par gravité et au tectonisme aux bordures de plaques qui se consument. La plupart des exemples mondiaux se réfèrent à l'obduction d'ophiolite et à la destruction de bordures continentales stables.

Le supergroupe de Fleur de Lys, dans la partie nord des Appalaches, consiste en roches sédimentaires, surtout clastiques, polydéformées et métamorphisées qui se sont accumulées le long de la bordure continentale stable de l'est de l'Amérique du Nord de l'Hadrynien au début du Paléozoïque. Les schistes verts au sommet ou près du sommet de la succession à l'est (complexe de Birchy) contiennent des zones de mélange ophiolitique typique. Ces zones consistent en d'immenses blocs de roches ultramafiques serpentinisées, des altérations actinote–fuchsite de blocs ultramafiques plus petits, des gabbros altérés, une variété de blocs sédimentaires clastiques et du marbre. Toutes ces roches ont subi la déformation à plusieurs reprises et sont métamorphisées de sorte que le mélange a été sujet à l'éventail complet des déformations du supergroupe de Fleur de Lys.

La présence de mélange ophiolitique polydéformé et métamorphisé dans le supergroupe de Fleur de Lys implique une dislocation ou une imbrication ancienne des ses unités lithologiques. On interprète la dislocation et la formation du mélange en relation avec le transport de complexes ophiolitiques, tels le complexe de Bay of Islands, sur un prisme de glacis continental initialement intact, le supergroupe de Fleur de Lys. La déformation polyphasée subséquente et le métamorphisme du supergroupe de Fleur de Lys résultent possiblement de la submergence structurale continue et le télescopage de la bordure continentale sous une couverture épaisse d'unités lithologiques ophiolitiques transportées.

[Traduit par le journal]

Can. J. Earth Sci., **14**, 987–1003 (1977)

Introduction

The Fleur de Lys Supergroup and similar rocks along the western margin of the Appalachian system are interpreted as a Hadrynian – Early Ordovician slope–rise prism of mainly clastic sediments built up along the early rifted margin of eastern North America (Williams and Stevens 1974). The rocks are polydeformed and metamorphosed in Newfoundland and the mechanism and timing of deformation and meta-

morphism are problems of long standing in the interpretation of the geologic evolution of the western margin of the Appalachian Orogen.

The Fleur de Lys Supergroup contrasts sharply in structural style with nearby volcanic groups and ophiolite suites to the east, and this has led to the commonly held opinion that the Fleur de Lys Supergroup was polydeformed before nearby ophiolite suites were generated (Church 1969; Dewey and Bird 1971; Kidd 1974; Kennedy 1973, 1975). A Late Cambrian age for its deformation is suggested by correlation of nearby ophiolite suites with the relatively undeformed Lower Ordovician Snooks Arm Group and underlying Betts Cove ophiolite complex. This age of deformation is supported also by distant correlation of the Fleur de Lys Supergroup with the Dalradian of Ireland (Kennedy *et al.* 1972), where deformed Fleur de Lys equivalents are interpreted to underlie Lower Ordovician strata.

To the west of the Fleur de Lys orthotectonic zone, the geology of western Newfoundland records the evolution of a stable continental margin that was destroyed by the westward transport of oceanic crust and emplacement of other allochthonous rocks in middle Ordovician time (Williams 1975). The idea of a Late Cambrian Fleur de Lys deformed zone seems at odds with several relationships in western Newfoundland as follows: (*a*) the evolution of a Cambrian–Ordovician carbonate sequence was uninterrupted; (*b*) Fleur de Lys correlatives in the Humber Arm and Hare Bay Allochthons were undeformed before transport; (*c*) flysch sequences related to transport are surprisingly free of metamorphic rock detritus; and (*d*) the most reasonable root zone for transported plutonic complexes such as the Little Port and Bay of Islands lies east of the presumed Late Cambrian Fleur de Lys deformed zone.

A study of the geology of Burlington Peninsula and White Bay was started in 1976 in an attempt to reconcile geologic relationships there with the structures and time of transport of allochthonous rocks in western Newfoundland.

The recognition of deformed ophiolitic mélanges within the Fleur de Lys Supergroup bears upon one of the major problems of Appalachian–Caledonian geology, *i.e.* the timing of deformation and metamorphism within the Fleur de Lys and comparable terranes (*e.g.* the Moine–Dalradian of the British Caledonides) in relation to the time of generation of nearby ophiolite suites and the time of their transport across an ancient continental margin. The Fleur de Lys Supergroup was undeformed at the time of formation of its ophiolitic mélanges. Since mélange formation involved the transport of ophiolite complexes, Fleur de Lys deformation and metamorphism either accompanied or followed the transport of such complexes.

Ophiolitic Mélange

Definition

Mélange (Greenly 1919) is a term presently used in a descriptive geologic sense for a chaotic mixture of unsorted blocks in a much finer, commonly sheared matrix. Ophiolitic mélange is a mixture of ophiolitic and sedimentary blocks, commonly with exotics of unknown provenance, set in either a shale–sandstone matrix or a matrix of tectonically sheared serpentinite. This term was introduced by Gansser (1974) with the aim of focussing attention on the close spatial and genetic relationship between mélange containing blocks derived from the ophiolite suite and transported ophiolite nappes.

A sedimentary matrix and the contrasting nature of plasticly deformed sedimentary blocks, resistant blocks, and a wide variety of exotic blocks, suggest an origin for many ophiolitic mélanges by surficial mass wastage. Other examples with sheared serpentinite matrix are truly tectonic mixtures. Recycling of tectonic mélange into sedimentary olistostromes and tectonic deformation of original sedimentary mélange obviously lead to difficulties in both classification and interpretation.

The writer prefers to view most examples of these mélanges as olistostromal mixtures of tectonically displaced rocks, but regardless of one's prejudices, ophiolitic mélange is a special rock type and its presence always provides an important adjunct to the interpretation of the geologic evolution of the area in which it is recognized.

Occurrence

Ophiolitic mélanges are restricted to ophiolite belts and like the ophiolite suite, they relate wholly to their environment of formation or place of deposition. They occur at ancient convergent plate boundaries, which in most cases are destroyed continental margins. Like rocks of the ophiolite suite, most ophiolite mélanges are

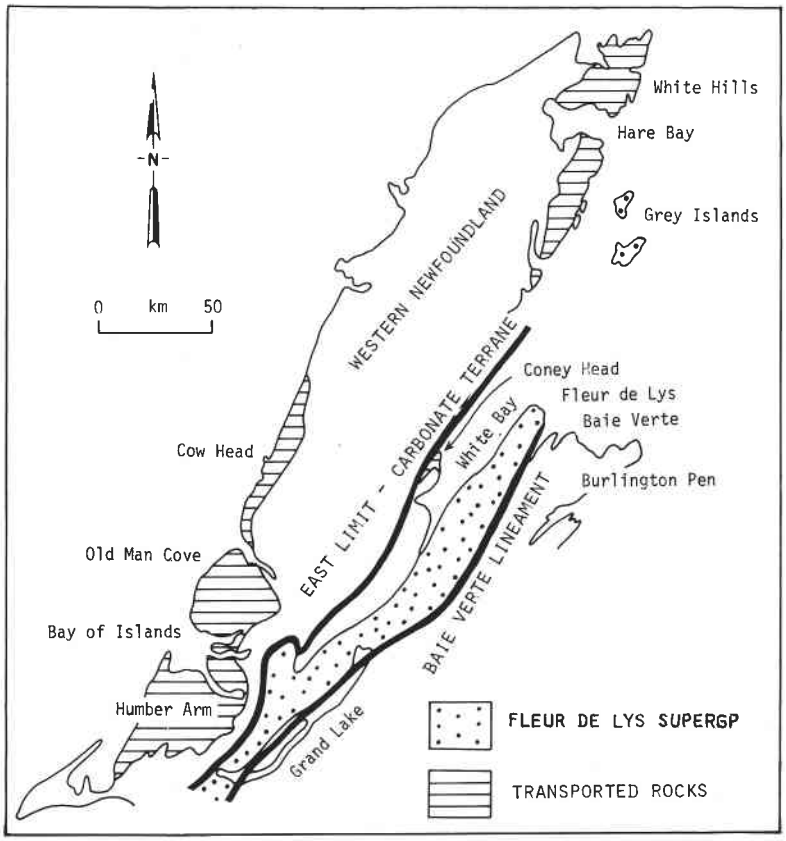

FIG. 1. The position of the Fleur de Lys Supergroup with respect to the major tectonic elements of western Newfoundland.

of Mesozoic or younger age, some are Paleozoic, and Precambrian occurrences are rare.

A review of Asian examples suggested to Gansser (1974) that ophiolitic mélanges are the result of obduction, *i.e.* the overthrusting of oceanic rocks across continental margins. This conclusion applies in the case of most examples with sedimentary matrices, but others with serpentinite matrix, or with associated blueschist metamorphism, are more likely subduction-related phenomena. Yet this distinction may be subtle in places where the polarity of subduction is away from a continental margin and where initial stages of obduction and final stages of subduction are one and the same process.

In areas of marked allochthonous character, ophiolitic mélanges occur between structural slices of sedimentary and plutonic rocks that collectively constitute composite allochthons. In most of these cases the uppermost ophiolitic mélange horizon is capped by an ophiolite nappe, *e.g.* Oman, Newfoundland, Urals, Himalayas, Zagros, etc. The presence of mélange in such places clearly indicates disruption and imbrication of a structural pile, and mélange formation obviously relates to the displacement and transport of the ophiolite suite.

Examples in Western Newfoundland

Ophiolitic mélanges occur in three distinct zones in western Newfoundland (Fig. 1). The best exposed and most extensive mélanges form parts of the Humber Arm and Hare Bay Allochthons, each of which includes an ophiolite sheet at its top (Stevens 1970; Williams 1975). Another example, Second Pond Mélange (Williams 1977) on the west side of White Bay, occurs above an autochthonous mainly carbonate sequence and is overlain by transported plutonic rocks of the Coney Head Complex. The third occurrence is within the Fleur de Lys Supergroup (Coachman's Mélange of Fig. 3)

and is followed eastward by imbricated ophiolites at the Baie Verte Lineament (Kidd 1974; Williams *et al.* 1977).

Deformation and metamorphism increase from west to east across the area of these mélange occurrences. Those associated with the Humber Arm and Hare Bay Allochthons are mainly thin subhorizontal sheets between other transported rocks that collectively lie above a relatively undeformed Cambro-Ordovician autochthonous carbonate sequence. The Second Pond Mélange occurs in a steep zone of Taconic structural telescoping, which was involved in later Acadian deformation. Ophiolitic mélange in the Fleur de Lys Supergroup is polydeformed and metamorphosed so that it now bears little resemblance to occurrences farther west.

All of these mélanges were possibly once continuous across western Newfoundland and are interpreted as the result of ophiolite transport and the destruction of the ancient continental margin of eastern North America.

Fleur de Lys Supergroup

Definition, Distribution, and Thickness

The Fleur de Lys Supergroup (Church 1969) is used here to refer to the polydeformed and metamorphosed rocks to the west of the Baie Verte Lineament (Figs. 1, 2), a steep structural zone marked by ophiolite complexes along its length. These rocks were first mapped and subdivided at Fleur de Lys (Fuller 1941) which is the type area. Watson (1947) assigned some of them to the Rattling Brook Group and all were assigned to the Fleur de Lys Group by Baird (1951), Neale and Nash (1963), and others. Rocks of similar structural style and metamorphic grade at southern White Bay were called the White Bay Group (Betz 1948).

Lithic correlatives of the rocks at Fleur de Lys occur 100 km to the northeast at Grey Islands (Kennedy *et al.* 1973), and 200 km to the southwest near Grand Lake (Fig. 1).

Fuller (1941) estimated the thickness of the sequence at 6 km and Kennedy (1975) suggested 7 km. A more accurate estimate is difficult because of structural complexity, but rocks similar to those in the Fleur de Lys Supergroup along the western margin of the Appalachian Orogen locally reach thicknesses of more than 10 km.

The Fleur de Lys Supergroup as defined by Church (1969) and used by most recent workers (Kennedy 1971, 1973, 1975; Dewey and Bird 1971; Kidd 1974; and others) included a variety of rocks to the east of the Baie Verte Lineament (Fig. 2). Some of these, *e.g.* Mings Bight Group (Baird 1951), resemble the Fleur de Lys in its type area. Others, *e.g.* Pacquet Harbour Group and northerly parts of the Cape St. John Group at Grand Cove (Church 1969), and the Cape Brulé Porphyry (Baird 1951), are mainly mafic and silicic volcanics that are unlike the rocks at Fleur de Lys.

The eastern Fleur de Lys (Church 1969), or that part of the Fleur de Lys Supergroup to the east of the Baie Verte Lineament, was always problematic. Some rocks there are polydeformed and metamorphosed, thus resembling in structural style the Fleur de Lys west of the lineament. Others are no more deformed and metamorphosed than nearby Ordovician and Silurian rocks, interpreted to postdate Fleur de Lys deformation (Neale and Kennedy 1967). Expansion of the eastern Fleur de Lys to include all of the Cape St. John Group (Dewey and Bird 1971; Kennedy 1973) led to further problems and a certain uneasiness among those familiar with the geology of the Burlington Peninsula. The Cape St. John Group was assigned previously to the Silurian and interpreted to overlie unconformably the fossiliferous Lower Ordovician Snooks Arm Group (Neale 1957). No structural or stratigraphic breaks are recognized among any rocks within the eastern Fleur de Lys from Cape St. John all the way westward to Ming's Bight. Assignment of the Cape St. John to the Fleur de Lys Supergroup thus demanded revisions in previous geologic interpretations.

Recent work has reconfirmed the Snooks Arm – Cape St. John unconformity (Neale *et al.* 1975; DeGrace *et al.* 1976; Williams *et al.* 1977). Still no break is recognized between the Cape St. John and other groups assigned to the eastern Fleur de Lys (DeGrace *et al.* 1976). The concept of an eastern Fleur de Lys, and correlation of rocks and structures across the important Baie Verte ophiolite zone, are therefore suspect. If there is an eastern Fleur de Lys, it cannot include all of the Cape St. John Group. If there is no structural or stratigraphic break between Cape St. John and Ming's Bight, there is no eastern Fleur de Lys as envisaged by its proponents.

In view of these uncertainties, and pending further work to clarify relationships among rocks to the east of the Baie Verte Lineament, the Fleur de Lys Supergroup is used here to denote

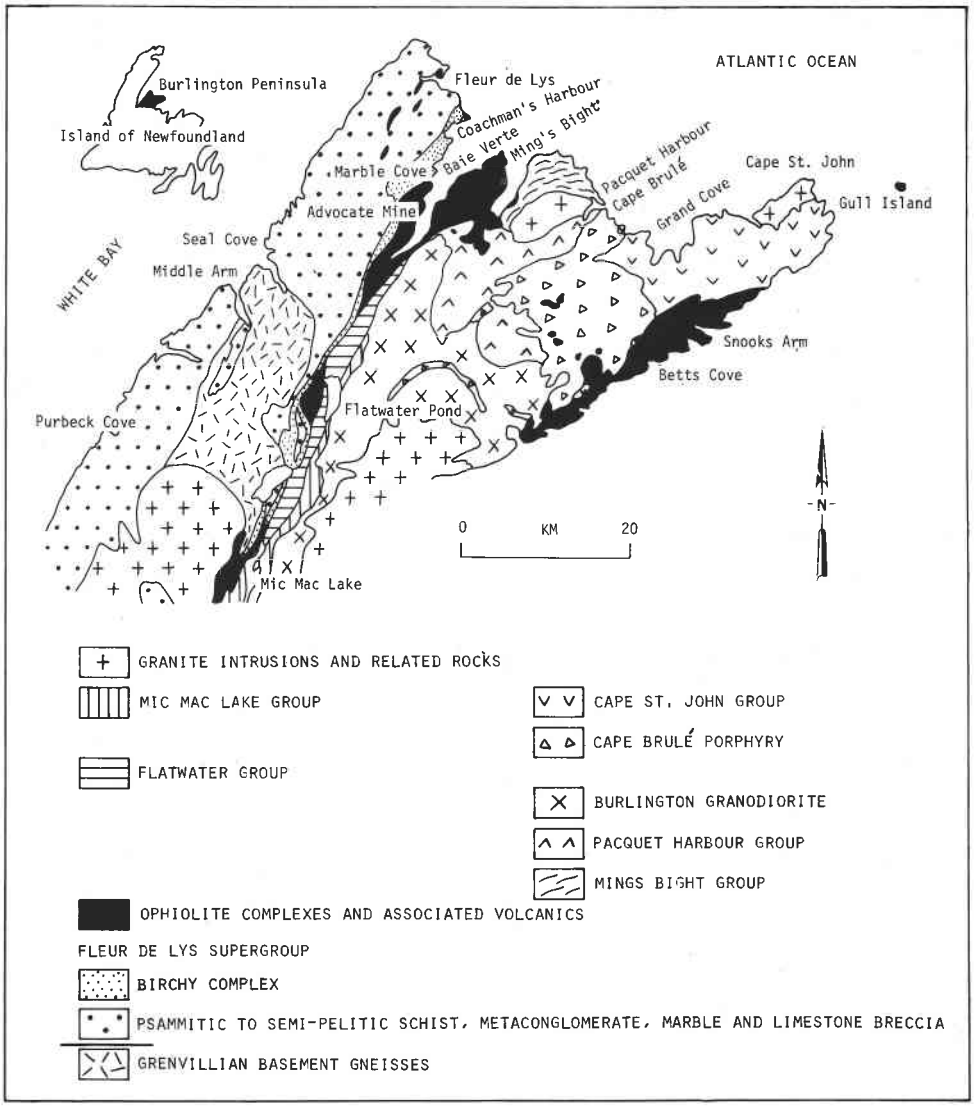

FIG. 2. General geology of the Burlington Peninsula, Newfoundland.

only those rocks to the west of the Baie Verte Lineament.

Greenschists of the Fleur de Lys Supergroup at Coachman's Harbour and southward were designated the Birchy Schist (Fuller 1941). Because this unit includes large serpentinite and metagabbro bodies, and ophiolitic mélange, it is viewed now as a mainly structural assemblage rather than a stratigraphic formation. Accordingly, it is renamed the Birchy Complex. Some greenschists of this complex are interlayered with psammitic and pelitic schists typical of the Fleur de Lys Supergroup. Other units such as igneous rocks of the ophiolite suite and ophiolitic mélange are obviously not a natural part of the Fleur de Lys stratigraphic succession. The eastern margin of the Fleur de Lys Supergroup may therefore require sharper definition, but according to the tradition of all previous workers, the Birchy Complex is viewed as an integral part of the Fleur de Lys terrane. Recent interpretations of the age and stratigraphic relationships of the Fleur de Lys Supergroup compared to nearby groups of the Burlington Peninsula are summarized in Table 1, and a comprehensive review is given by DeGrace *et al.* (1976).

TABLE 1. Summary of recent interpretations of age and stratigraphic relationships among rock groups of the Burlington Peninsula. Solid bar indicates time of earliest deformation. West and east refer to localities on opposite sides of the Baie Verte Lineament

	Neale and Nash 1963		Neale and Kennedy 1967		Church 1969		Kidd 1974 Dewey and Bird 1971		Kennedy 1975		Bursnall and DeWit 1975		DeGrace et al. 1976		Williams et al. 1977	
	West	East	West	East	West	East	West	East	West	East	West	East	West	East	West	East
Silurian Devonian	Mic Mac Lake Seq.	Cape St. John Group	Baie Verte Group Mic Mac Lake Seq.	Cape St. John Group	Cape St. John Group		Mic Mac Lake Group		Mic Mac Lake Sequence					Cape St. John Group	Mic Mac Lake Group	Cape St. John Group
Ordovician	Baie Verte Group	Snooks Arm Group		Snooks Arm Group	Baie Verte Group	Snooks Arm Group	Baie Verte Group	Snooks Arm Group	Baie Verte Group	Snooks Arm Group			B.V. Gp.	Pacquet Hr. Group Snooks Arm Group	Flatwater Group	Pacquet Hr. Group Mings Bight Group
Late Precambrian - Cambrian	Fleur de lys Group	Mings Bight Group (included with Fleur de Lys)	Fleur de lys Group	Pacquet Hr. Group Mings Bight Group	Fleur de Lys Supergroup Rattling Bk - White Bay Groups	Grand Cove Group Pacquet Hr. Group Mings Bight Group	Fleur de Lys Supergroup	Cape St. John Group Pacquet Hr. Group Mings Bight Group Nippers Harbour Group	Fleur de Lys Supergroup Advocate Sequence Flat Point Formation Birchy Schist Harbour Seq. White Bay Seq.	Cape St. John Group Pacquet Hr. Group Mings Bight Group	Fleur de Lys Supergroup Baie Verte Group	Mings Bight Group Snooks Arm Group	Fleur de Lys Supergroup	Mings Bight Group	Fleur de Lys Supergroup Birchy Complex Advocate Complex Point Rousse Complex	Mings Bight Group

Lithology

The Fleur de Lys Supergroup consists of semipelitic and psammitic schists with minor graphitic pelites, marbles, limestone breccias, conglomerates, and greenschists of mafic volcanic parentage. Psammitic schists occupy its central parts south of Fleur de Lys (Fig. 2). Marbles and limestone breccias are most common to the south of Purbeck Cove in western exposures, and greenschists occur along its eastern margin south of Coachman's Harbour. A coarse metaconglomerate with clasts of quartzite and granite gneiss occurs to the south of Middle Arm.

Ophiolitic mélange within the Fleur de Lys Supergroup is contained in greenschists of the Birchy Complex along its eastern margin. These are green to greyish green, strongly schistose rocks, which are speckled with small magnetite octahedra. They are made up of chlorite, actinolite, albite, epidote, quartz, and carbonate.

Hornblende amphibolites, in places garnetiferous, are common throughout the Fleur de Lys psammitic schists, especially in western exposures near Seal Cove. These are metamorphosed mafic dikes and plugs that are now isolated as boudins on fold limbs or as more equidimensional bodies in hinge zones.

Small bodies of eclogite occur throughout an area of deformed gneisses southeast of Middle Arm. The gneissic rocks are interpreted as Grenvillian basement beneath a Fleur de Lys cover and associated eclogites are interpreted as mafic intrusions like those in nearby psammitic schists (De Wit 1972). Contrasts in metamorphic facies are interpreted to reflect anhydrous conditions during metamorphism in basement rocks (eclogite facies) compared to more hydrous amphibolite facies conditions in the cover sequence (De Wit and Strong 1975).

For more detailed lithic descriptions the reader is referred to papers by Neale and Kennedy (1967), Church (1969), Kennedy (1971), De Wit (1972, 1974), and Bursnall (1975).

Stratigraphy

No continuous stratigraphic succession has been worked out for the entire Fleur de Lys Supergroup. Local successions have been determined in the west (De Wit 1972) and in the east (Bursnall 1975), and three sequences separated by faults are recognized between Fleur de Lys and Coachman's Harbour in the north (Kennedy 1971, 1975). In the west, psammitic schists and metaconglomerates are interpreted as basal parts of the supergroup where they surround deformed basement gneisses (De Wit 1974). Nearby marbles and lime breccia units occur higher in the stratigraphic section. In the east, greenschists of the Birchy Complex are interpreted as underlying psammitic schists of the Flat Point Formation at Coachman's Harbour (Kennedy 1971), but farther east the complex is bordered by structural slices of ophiolitic rocks that define the Baie Verte Lineament.

The occurrence of carbonate units in the west and greenschists in the east appears to be an important lithic variation across the Fleur de Lys outcrop belt.

Structure and Metamorphism

Three phases of intense deformation are recognized in the Fleur de Lys Supergroup (Kennedy 1975). The prominent fabric is a second schistosity, which consists of micaceous layering that was formed by transposition of an earlier schistosity. It is axial planar to major recumbent folds and these are in turn affected by later folding. In the northwest, the second schistosity is gently dipping and second phase recumbent folds face between northwest and northeast (Kennedy 1975). Farther east, the second schistosity is steeply dipping.

No large-scale first-phase folds are recognized within the Fleur de Lys, and the absence of bedding reversals or repetition of formations within second-phase structures, makes their presence unlikely. However, the first deformation did lead to the formation of major tectonic dislocations that locally predate the earliest schistosity (Kennedy 1975).

Later structures are reflected by strain-slip fabrics with associated tight upright folds. These are best developed in the east and become less intense northwestward toward the area of gently dipping second schistosity at Fleur de Lys.

Second-phase structures and third- and fourth-phase structures all increase in intensity toward the southeast. This may reflect either easterly downbuckling of original recumbent structures that increased in intensity upwards, or else the intensity of deformation increases southeastward and laterally from the vicinity of Fleur de Lys toward the Baie Verte Lineament (Kennedy 1975).

Metamorphism of the Fleur de Lys Super-

group is for the most part typical of greenschist and amphibolite facies. Most psammitic rocks are biotite–muscovite–albite schists, garnetiferous mica schists, and locally kyanite- and staurolite-bearing schists. Mafic volcanic and intrusive rocks are now either greenschists or amphibolites. The highest grade metamorphic rocks occur in the central parts of the outcrop belt, rather than at its margins. Metamorphic intensity thus shows a reversed distribution compared to intensity of deformation (Kennedy 1975).

Age and Correlation

No fossils are known in the Fleur de Lys Supergroup and its age is dependent upon lithic correlation. Certainly its rocks are younger than Grenvillian basement, but an upper limit for the age of its youngest rocks is difficult to ascertain. Thick psammitic basal units resemble the Lower Cambrian or older Maiden Point and Summerside Formations of the Hare Bay and Humber Arm Allochthons respectively (Williams 1975). Carbonate breccias along its western margin are similar to those of the Middle Cambrian to middle Ordovician Cow Head Group (Kindle and Whittington 1958) and suggest that some of its rocks are of equivalent age (Bursnall and De Wit 1975). Along its eastern margin, some rocks of the Birchy Complex resemble deformed rocks of ophiolitic complexes at Baie Verte. These ophiolites are undated, but like others in Newfoundland, they are interpreted as Early Ordovician or older in age.

Dating of the deformation and metamorphism of the Fleur de Lys Supergroup also relies heavily on indirect evidence. If its carbonate breccias are Cow Head equivalents, its deformation may be as young as early middle Ordovician (Bursnall and De Wit 1975).

An undated mainly volcanic sequence to the east of the Fleur de Lys Supergroup at Flatwater Pond (informal Flatwater group of Williams *et al.* 1977) contains a large clast of semi-pelitic schist in a basal conglomerate unit. The clast is interpreted as derived from the Fleur de Lys Supergroup (Kidd 1974). The Flatwater conglomerate also contains deformed clasts derived from the ophiolite suite of rock units, so that it is also interpreted as younger than the earliest deformation in nearby ophiolite complexes such as those at Baie Verte (Williams *et al.* 1977). The age of the Flatwater group is unknown, apart from the fact that it is overlain by Silurian–Devonian rocks of the Mic Mac Lake Group (Kidd 1974), but its similarity to nearby volcanic groups suggests a middle Ordovician or older age.

$^{40}Ar/^{39}Ar$ isotopic ages of metamorphic minerals from the Fleur de Lys Supergroup indicate cooling at about 400 Ma (R. D. Dallmeyer, personal communication, 1976).

Church (1969) reported rock fragments of pelitic schist, actinolite schist, and rhyolite in the Lower Ordovician Snooks Arm greywackes that resemble schists and rhyolites of the Pacquet Harbour Group and nearby parts of the Cape St. John Group, *i.e.* Grand Cove Group of Church (1969). The Snooks Arm Group (Snelgrove 1931) overlies the Betts Cove ophiolite complex (Upadhyay *et al.* 1971) and this report of Fleur de Lys metamorphic detritus in Lower Ordovician clastics is widely quoted in support of the view that Fleur de Lys deformation and metamorphism preceded Early Ordovician ophiolite generation (Church 1969; Kennedy 1973, 1975). However, the concept of an eastern Fleur de Lys that includes the Pacquet Harbour and Cape St. John Groups is now suspect, and metamorphic detritus in Snooks Arm greywackes may have little relevance in dating deformation and metamorphism in the far-removed Fleur de Lys rocks to the west of the Baie Verte Lineament.

Interpretation

The position of the Fleur de Lys Supergroup with respect to Grenvillian inliers and a Cambro-Ordovician carbonate sequence to the west, and ophiolite suites to the east, suggests that it represents the initial deposits built upon the ancient rifted margin of eastern North America (Williams and Stevens 1974). Mafic intrusions that are common in its lower psammitic parts possibly relate to earliest rifting, and these may correlate with mafic dikes that cut Grenvillian basement and its oldest cover rocks farther west (Strong and Williams 1972). Marbles and limestone breccias in westerly exposures may represent easterly distal facies of the Early Paleozoic carbonate bank that evolved at the stable continental margin (Neale and Nash 1963; Rodgers 1968). Greenschists common in easterly exposures may represent the distal facies of oceanic volcanic rocks that are widespread to the east of the Baie Verte Lineament. The Fleur de Lys

Supergroup is viewed therefore as a thick prism of continental slope–rise sediments, which range in age from late Precambrian (Hadrynian) to Early Ordovician and possibly early middle Ordovician.

Ophiolitic Mélange in the Fleur de Lys Supergroup

Distribution and Thickness

Ophiolitic mélange has been recognized within the Birchy Complex. The chaotic rocks are well exposed at Coachman's Harbour and are therefore designated the Coachman's Mélange. All previous workers assigned these rocks to the Fleur de Lys Supergroup; associated greenschists can be traced several tens of kilometres to the south and are present also at Grey Islands, 100 km to the north (Kennedy *et al.* 1973).

The Coachman's Mélange is exposed in at least six localities along the south shore of Coachman's Harbour and at an additional five localities on the north shore of the harbour (Fig. 3). The mélange zones are narrow and rarely more than 50 m in structural thickness. Northward along strike at Big Pardee Cove, the mélange outcrops at another five localities, and is also exposed at Slaughter House Cove.

At Coachman's Harbour and Slaughter House Cove, greenschists of the Birchy Complex are infolded with psammitic schists of the Flat Point Formation (Kennedy 1971). Major upright second-phase folds are interpreted as facing northward, *e.g.* Big Pardee Cove (Fig. 3), so that greenschists of the Birchy Complex are interpreted as underlying the Flat Point psammites (Kennedy 1971; Bursnall 1975). However, facing criteria are rare and unconvincing, and brief examinations of some contacts with John Bursnall in 1976 failed to convince the present writer of this stratigraphic relationship.

All occurrences of the Coachman's Mélange at Coachman's Harbour may represent a single unit repeated by folding. If so, some exceedingly tight isoclines of 3 km amplitude are localized within the Birchy Complex, which are not expressed in the geometry of the Birchy Complex greenschists – Flat Point Formation contact. More likely, the mélange occurs in several different zones that are repeated by folding.

Description of Coachman's Mélange

The Coachman's Mélange has a black pelitic matrix with conspicuous deformed and recrystallized ultramafic blocks now represented by bright green actinolite–fuchsite schist. Sedimentary blocks with ill-defined outlines are common everywhere, and in some places large serpentinized ultramafic blocks, foliated gabbro blocks, and marble are also known.

Actinolite–fuchsite schist occurs in lenses from 10 cm to 3 m in length and rarely more than 1 m in width (Fig. 4). They exhibit minor folds and folded schistosities identical to structures in the surrounding schistose matrix and nearby greenschists. Pale green actinolite crystals are locally 2–4 cm in length, set in a fine-grained fuchsite–carbonate matrix. An ultramafic origin for these rocks is indicated by their mineralogy and because larger nearby ultramafic blocks are recrystallized to similar mineral assemblages at their margins.

Ultramafic blocks more than 1 m in width are preserved as brownish weathering serpentinites. One occurrence on the north shore at Coachman's Harbour is 2 m by 6 m and another at a picnic site between Deep Cove and French Island is equidimensional and 50 m across (Figs. 3, 5). The latter is internally brecciated, and this feature predates both serpentinization and incorporation into the mélange.

Blocks of sedimentary protolith are now represented by light to dark grey and buff psammitic and semi-pelitic schists. Some of these contrast with the surrounding dark grey to black matrix (Fig. 6), but most appear as folded lenses that resemble beds. A conspicuous white infolded marble block occurs in the mélange between Deep Cove and French Island and quartzite clasts occur in a similar mélange at Slaughter House Brook.

A distinctive unit of amphibole–plagioclase–epidote–quartz schist occurs within the Birchy Complex at South Cove of Coachman's Harbour and can be traced 3 km southward to Slaughter House Cove. Although originally mapped as metadiorite or metagabbro (Watson 1947; Neale 1959), more recent workers interpret the unit as sedimentary and a stratigraphic formation, the South Cove Schist (Kennedy 1971; Bursnall 1975). Less deformed examples of this rock, which are preserved as large boudins in more schistose rock, resemble metagabbro (Fig. 7), and serpentinized ultramafic rocks occur within the unit near Slaughter House Cove. This

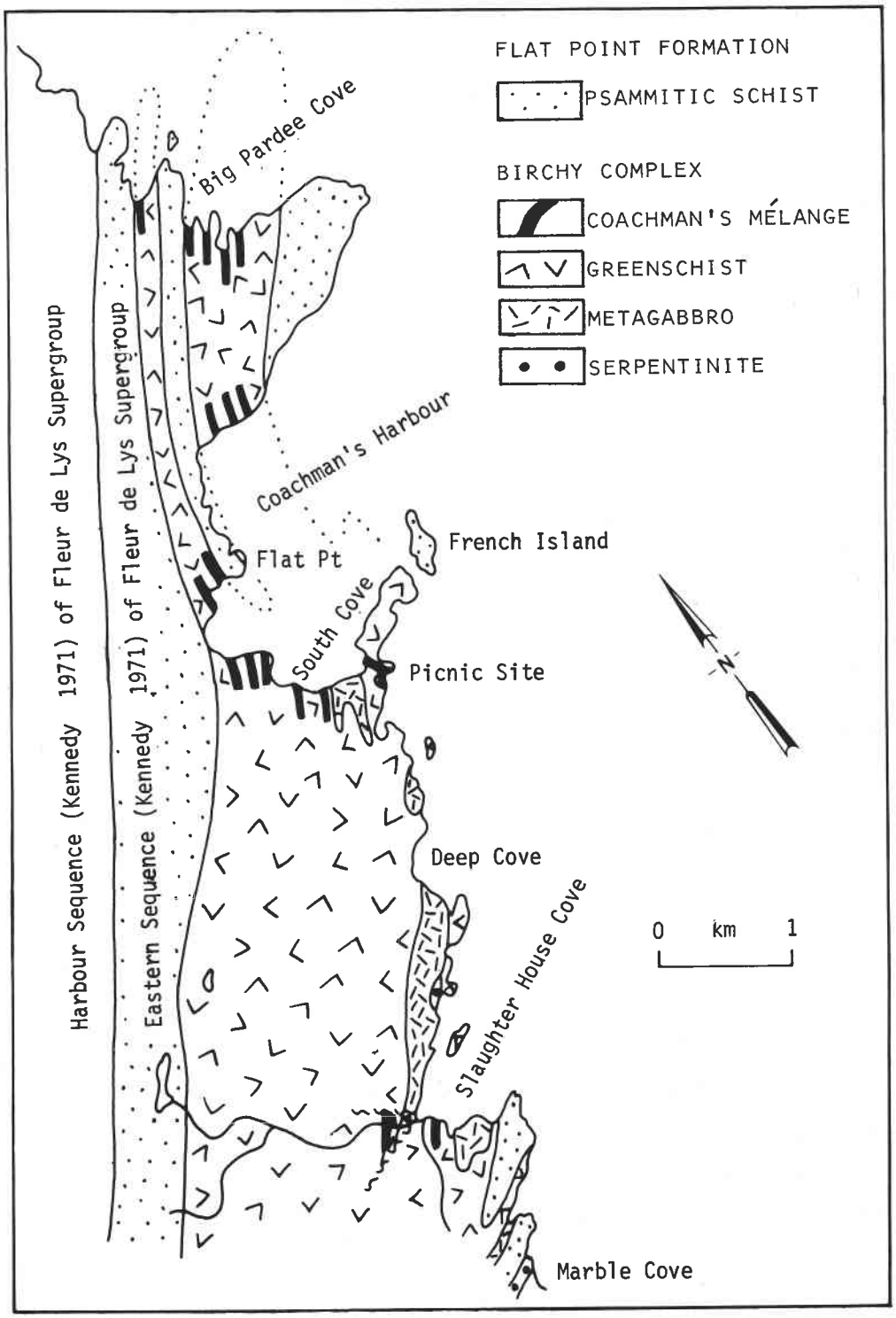

FIG. 3. Distribution of ophiolitic mélange in the Birchy Complex at Coachman's Harbour.

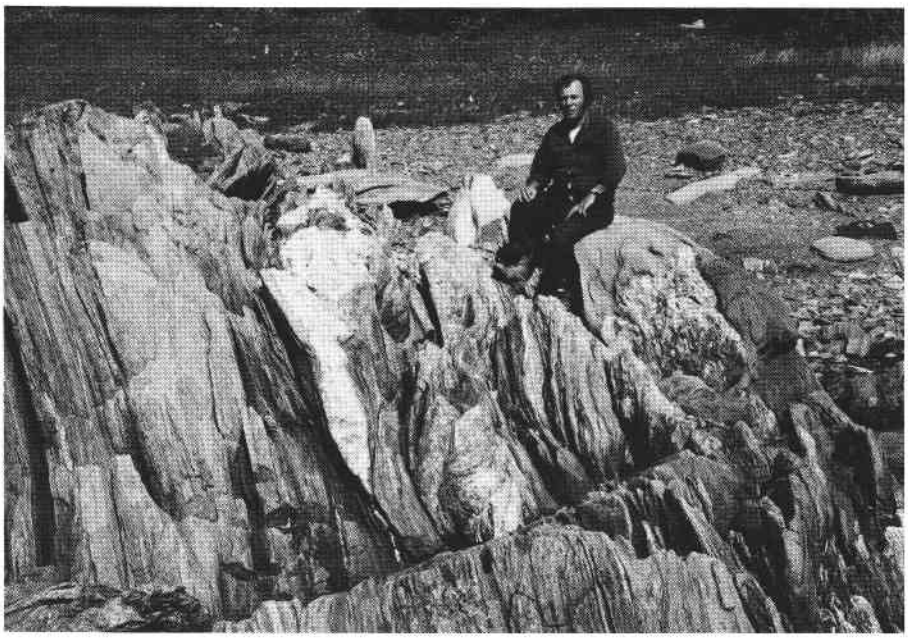

FIG. 4. Actinolite–fuchsite schist lenses in ophiolitic mélange immediately west of Flat Point, Coachman's Harbour.

FIG. 5. Internally brecciated serpentinite block in ophiolitic mélange at Picnic Site, Coachman's Harbour.

FIG. 6. Black pelitic ophiolitic mélange with mainly sedimentary clasts, Picnic Site at Coachman's Harbour.

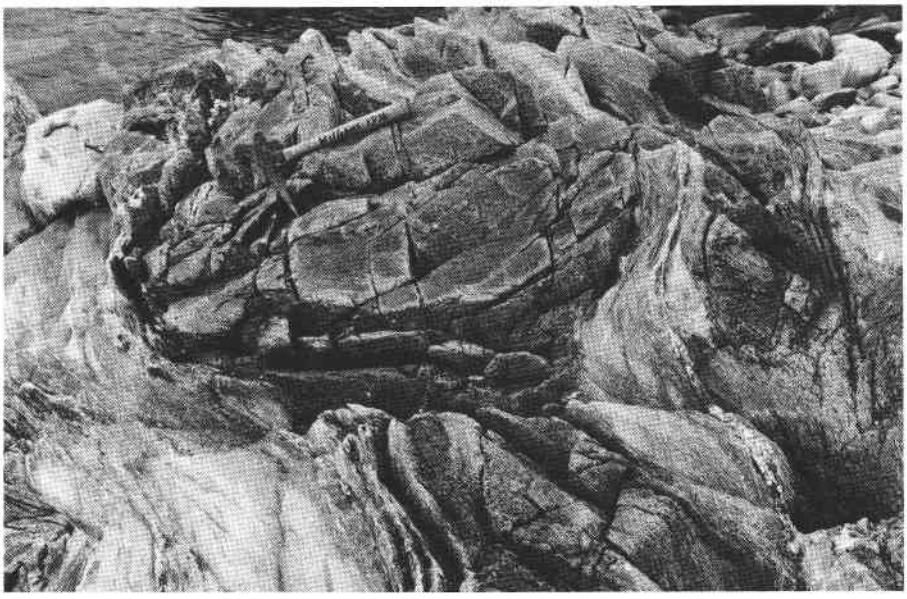

FIG. 7. Foliated metagabbro boudins in schistose metagabbro of South Cove Schist, 1 km north of Slaughter House Cove.

suggests an igneous origin, and possibly these rocks represent a tectonic inclusion within the Birchy Complex.

Significance

The presence of ophiolitic mélange within the Birchy Complex, affected by the full sequence of Fleur de Lys deformations, implies a disruption and structural imbrication of its rock units that preceded polyphase deformation and metamorphism within the Fleur de Lys Supergroup. Ophiolite must have been exposed at the surface

to supply the blocks so evident in the mélange, so that disruption and imbrication relate most reasonably to ophiolite transport. Similar mélanges with black shale matrix, though with fewer ophiolite blocks in most examples, separate structural slices and are associated with ophiolite transport in western Newfoundland (Williams 1975).

Black pelitic zones with conspicuous actinolite–fuchsite schist lenses were recognized within the Birchy Complex by most previous workers (Watson 1947; Kennedy 1971; Bursnall 1975). However, their present interpretation as ophiolitic mélange imparts a new and considerable significance to these rocks. As in the case of other worldwide examples, the ophiolitic mélanges at Coachman's Harbour imply the transport of an ophiolite suite across the local Fleur de Lys terrane. This ophiolite transport is equated most reasonably with the emplacement of the Bay of Islands Complex from an original position east of the Baie Verte Lineament to its present position in western Newfoundland. Similar structural histories for both the Coachman's Mélange and nearby parts of the Fleur de Lys Supergroup indicate that the Fleur de Lys was undeformed at the time of mélange formation and initial ophiolite displacement. This conclusion leads to a simple model for the place of origin and time of transport of ophiolite complexes in western Newfoundland compared to the time of deformation and metamorphism in the intervening Fleur de Lys terrane (Fig. 8). As well, it explains the marked structural contrasts between the Fleur de Lys Supergroup and nearby ophiolite suites, while implying a mechanism for polyphase deformation and metamorphism in the affected rocks.

Small ultramafic and gabbroic bodies (Fig. 2), in a zone that extends from Fleur de Lys Harbour southward through the central psammitic part of the Fleur de Lys belt (Neale 1959), may also be localized along an early structural surface, rather than representing small high-level intrusions (Kennedy and Phillips 1971). If so, their presence implies further structural telescoping and imbrication across the Fleur de Lys terrane.

Relationship Between the Birchy Complex and Nearby Ophiolite Complexes

The Birchy Complex is bordered to the east by an imbricated ophiolite complex that extends south of Baie Verte and defines the Baie Verte Lineament. The ophiolitic rocks were included in the previous Baie Verte Group (Watson 1947; Baird 1951; Neale and Nash 1963; Neale and Kennedy 1967; Church 1969; Dewey and Bird 1971; Kennedy 1973, 1974) and they were interpreted to postdate deformation and metamorphism of the nearby Birchy Complex (Neale and Kennedy 1967; Church 1969; Dewey and Bird 1971; Kennedy 1973; Kidd 1974). However, the contact between the Birchy Complex and previous Baie Verte Group was always enigmatic and difficult to locate, chiefly because the Birchy Complex includes gabbro and ultramafic rocks like those near Baie Verte, and the Baie Verte Group included greenschists near Marble Cove and elsewhere that resemble greenschists of the Birchy Complex.

More recently all the ophiolitic rocks to the west of Baie Verte were designated the Advocate Sequence (Kennedy 1975) and interpreted as an integral part of the Fleur de Lys Supergroup, sharing the same structures as the Birchy Complex farther west. Other ophiolitic rocks to the east of Baie Verte were interpreted as younger than deformation in the Birchy Complex and Advocate Sequence (Kennedy 1975).

Bursnall (1975) has produced by far the most detailed map of the problematic area between Coachman's Harbour and Baie Verte. He divided the rocks into four main groups, which from north to south are the Birchy Schist Group, Marble Cove Sequence, Advocate Complex, and Shark Point Group. All are affected by numerous steep faults of several generations that are marked by zones of intense deformation. According to this subdivision, the important Birchy Schist – Baie Verte contact of previous workers, and the contact between the Birchy Schist and Advocate Sequence of Kennedy (1975), lie between the Birchy Schist Group and the Marble Cove Sequence. Yet the Marble Cove Sequence consists mainly of Birchy-type greenschist in coastal exposures that contrasts sharply with recognizable pillow lavas at Shark Point 1 km farther south. Similarly, the contact between ophiolites to the west of Baie Verte and those to the east is also difficult to define, and locally the easterly examples are just as intensely deformed as those to the west.

The overall structural picture suggests westward imbrication of east-facing ophiolitic suites, with intense deformation in lower zones (west of Baie Verte) and less intense deformation and

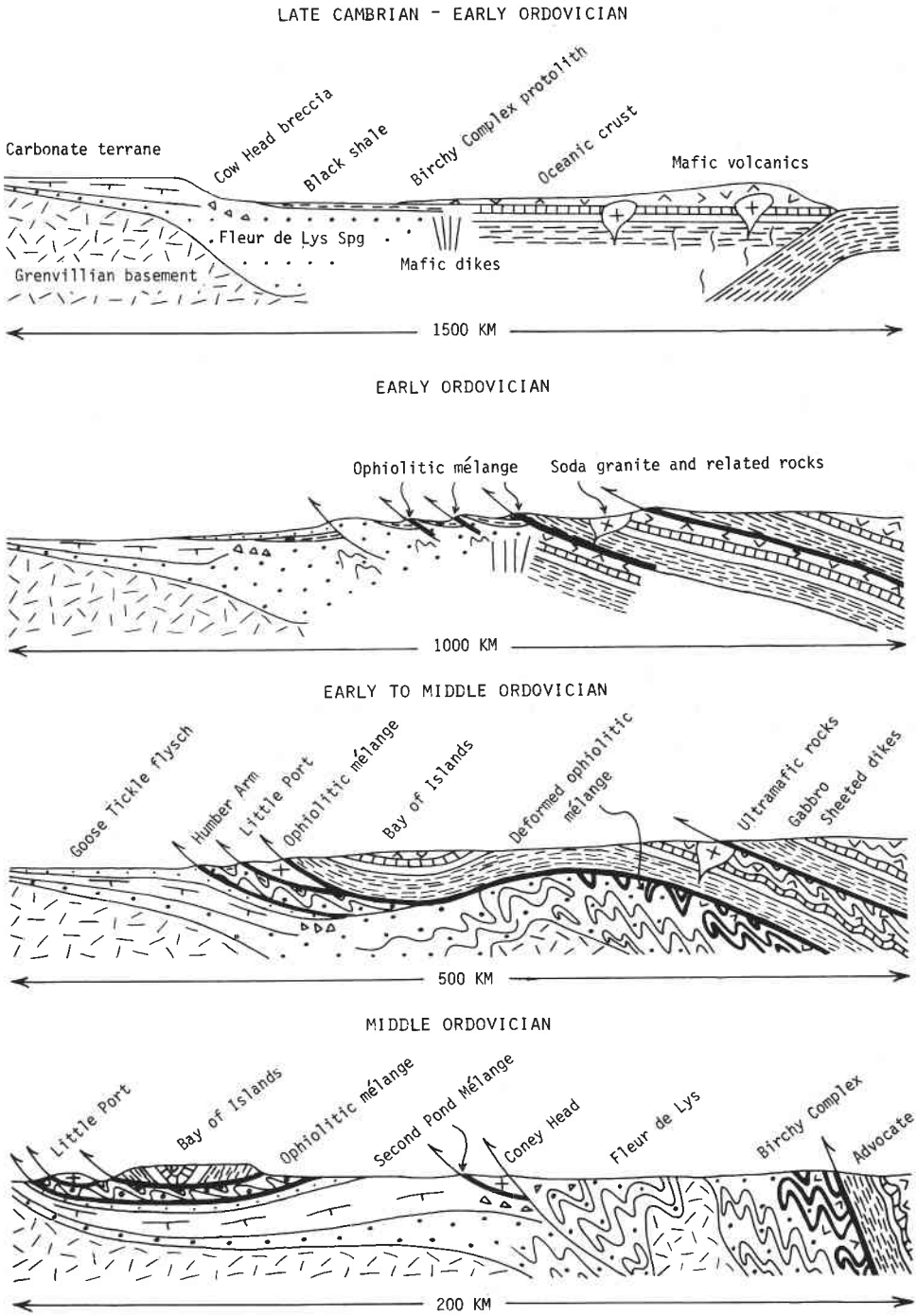

FIG. 8. A model for the development of ophiolitic mélange in the Birchy Complex and the relationships of mélange formation to ophiolite transport and time of deformation of the Fleur de Lys Supergroup.

fewer deformed zones higher in the structural pile (east of Baie Verte). At Marble Cove and southward, some zones of intense deformation contain black slaty to schistose rocks interpreted as original argillites incorporated tectonically along surfaces of major dislocation (Williams *et al.* 1977). Dismembered ophiolites and ophiolitic mélanges within the Birchy Complex occupy the lowest and most deformed level in this structural sequence.

Tectonic Interpretation

Ophiolitic mélanges in the Birchy Complex are followed eastward by an imbricated ophiolite suite that defines the Baie Verte Lineament. The Fleur de Lys Supergroup to the west is interpreted as a slope–rise prism of sediments deposited at the ancient continental margin of eastern North America. Ophiolites along the Baie Verte Lineament represent oceanic crust and mantle (Church and Stevens 1971). Ophiolitic mélanges within the Birchy Complex are situated therefore at or near an ancient continent–ocean interface. There they are interpreted as recording the effects of transport of oceanic crust westward across the continental margin.

The Birchy Complex was undeformed at the time of formation of its ophiolitic mélanges. It follows that the Fleur de Lys Supergroup was an essentially undeformed continental margin deposit during earliest ophiolite transport. Clearly the ophiolites were derived from the east of the Fleur de Lys terrane where excellent examples are still preserved. The Baie Verte Lineament is therefore the closest possible root zone for transported ophiolites such as the Bay of Islands Complex in western Newfoundland. Since the ophiolites were transported across an undeformed continental margin, there is no need to appeal to a White Bay root zone for the transported Bay of Islands Complex (Dewey and Bird 1971; Kidd 1977).

Greenschists similar to those of the Birchy Complex form the structural metamorphic aureoles of western Newfoundland transported ophiolites and other plutonic complexes, *e.g.* Goose Cove Schist at Hare Bay (Williams and Smyth 1973), Murrays Cove Schist (Williams 1977) along the western margin of the Coney Head Complex in western White Bay, Old Man Cove Formation (Williams 1975) of the Humber Arm Allochthon. This implies that all of the higher plutonic slices of the Humber Arm and nearby allochthons passed through or across a terrane such as that represented by the Birchy Complex at the Baie Verte Lineament. The formation of ophiolitic mélange and imbrication within the Birchy Complex are therefore to be expected. Lithic and structural similarities between greenschists of the Birchy Complex and aureole rocks beneath transported igneous complexes in western Newfoundland are also expectable, and it is significant in this context that the structural aureoles were imprinted upon undeformed rocks (Williams and Smyth 1973).

If the Birchy Complex is mainly a structural assemblage that includes ophiolite and ophiolitic mélanges, it is easy to explain the difficulties encountered in attempts to define a contact between the Birchy Complex and deformed, imbricated ophiolite suites to the east on structural grounds. Since the Baie Verte Lineament appears to be the root zone for transported ophiolites, it may be not at all fortuitous that deformation in the Fleur de Lys Supergroup increases in intensity toward the Baie Verte Lineament whereas its most intense metamorphism is recorded farther west and presumably deeper in the structural pile.

The main protolith of the Birchy Complex is mafic volcaniclastic and flow rocks, which at deposition may have been the distal equivalents of mafic volcanics like those above the Baie Verte ophiolite suites. It included clastic sedimentary rocks as well. Similarly, the Goose Cove Schist beneath the White Hills Peridotite passes downward into undeformed mafic volcanic rocks of the Ireland Point Formation, and locally at Fishot Islands, it includes clastic sedimentary rocks, the Fishot Islands Member of the Goose Cove Schist (Williams and Smyth 1977).

All of the ophiolitic suites of the Burlington Peninsula may relate to a single cycle of generation. They are interpreted as originating in a small ocean basin (Williams *et al.* 1977), mainly because they are all of similar age, where dated, and they occur in association with synchronous granitic complexes generated during subduction and convergent plate motions (Williams *et al.* 1976). Abandonment of the term Baie Verte Group, and suggested redefinition and reinterpretation of some of its rocks, *e.g.* Flatwater group (Williams *et al.* 1977) as younger than the earliest deformations in nearby ophiolite complexes, eliminates the necessity of interpreting all of the previous Baie Verte Group and its

ophiolites as younger than deformation and metamorphism in the Fleur de Lys Supergroup (Williams *et al.* 1977).

The geologic evolution of the Burlington Peninsula, west of the Baie Verte Lineament, and its relationships to the geologic evolution of western Newfoundland are summarized in Fig. 8. The eastern Fleur de Lys (Church 1969) is excluded from this analysis as structures and metamorphism in rocks to the east of the Baie Verte Lineament may relate to a different and younger orogenic cycle.

Ophiolitic mélanges like those in the Fleur de Lys Supergroup are unknown elsewhere in the Appalachian Orogen. Yet the Baie Verte Lineament appears to be a continuous feature marked by ophiolite complexes that extend through the Quebec Appalachians and southward into Vermont (St. Julien *et al.* 1976). Analogues may occur therefore among the deformed rocks immediately northwest of this ophiolite zone. Small ultramafic bodies associated with metamorphic rocks that occur along the western margin of the Appalachian Orogen should be examined as possible examples of ophiolitic mélange.

Acknowledgements

The author greatly appreciates financial support for his work in Newfoundland through a Sir Isaac Walton Killam Senior Research Scholarship, through Grant 85-650 of the National Research Council of Canada, and through Research Agreement 1135-D13-4-130/76 of the Department of Energy, Mines and Resources.

He also wishes to thank J. T. Bursnall, W. S. F. Kidd, J. P. Hibbard, and E. C. Appleyard for discussion in the field, and M. J. Kennedy, who first pointed out to him the common occurrence of deformed actinolite–fuchsite lenses in the Birchy Complex many years ago.

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