Current Research (1986) Newfoundland Department of Mines and Energy, Mineral Development Division, Report 86-1, pages 147-160

ORDOVICIAN SEDIMENTARY STRATA OF THE PISTOLET BAY AND HARE BAY AREA, GREAT NORTHERN PENINSULA, NEWFOUNDLAND

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ABSTRACT

Autochthonous Ordovician carbonate and siliciclastic rocks occur between Cambrian dolostones in the west and allochthonous sedimentary rocks of the Northwest Arm Formation in the eastern part of the map area. The Lower Ordovician St. George Group comprises four formations, the Watts Bight, Boat Harbour, Catoche and Aguathuna formations. Four lithologic members are delineated in the Catoche Formation within undolomitized parautochthonous strata. The members, in ascending order, are: 1) lower burrowed limestone, 2) middle mound, 3) upper burrowed limestone, and 4) white limestone. The Aguathuna Formation, which is mapped in this area for the first time, is thin and appears to rest disconformably upon the Catoche Formation. The Table Head Group comprises only the Table Point, Black Cove and Cape Cormorant formations. Fenestral limestones form an important member at the base of the Table Point Formation.

A number of erosional disconformities occur near the top of the St. George Group and the base of the Table Head Group. Growth faults breached the platform during the late Arenig, coinciding with regression on the platform and later early Llanvirn transgression. Shale-filled fissures, erosion and cementation at the top of the Table Point limestone, and abundance of Table Head-derived limestone breccias and possible olistoliths, suggest the area preserves the complex final stages of the Ordovician platform. The carbonates were succeeded by Middle Ordovician flysch, which flooded southwestward into the area.

Deformation began with the emplacement of Lower Ordovician mélange (Northwest Arm Formation) over the flysch basin and westward thrusting of parautochthonous limestones. This was followed by a later phase of compression in which a penetrative cleavage, westward-verging thrusts, northeast-trending, upright to overturned folds, and overthrusting, deformed the eastern half of the carbonate terrane, the flysch basin and the overlying mélange. The carbonate terrane was later extensively block faulted by northeast-, northwest-and west-trending high-angle faults.

Widespread sphalerite mineralization occurs in the Boat Harbour and Catoche formations within matrix breccias and secondary dolostones. Formation of cavern breccias and widespread dolomitization may have been partly controlled by the growth faulting that dissected the platform during late Arenig regression and karstification.

INTRODUCTION

Sedimentary rocks of Ordovician age underlie carbonate barrens, flat-lying peatbogs and the shoreline of Hare Bay and Pistolet Bay on the Great Northern Peninsula. Carbonate rocks of Early and Middle Ordovician age form a narrow south-trending belt of autochthonous and parautochthonous strata in the west. This belt is typified by extensive rock barrens, shallow peatbogs and tangled to open evergreen woodland. Topographic relief is generally low, but west of Hare Bay, limestone ridges rise up to 60 m above valleys of peatbog that occur just above sea level. To the east, the shore of Pistolet Bay and Hare Bay, and extensive lowlands between the bays, are underlain by folded, autochthonous, shaly flysch and some allochthonous sedimentary strata; the latter form the western leading edge of the Hare Bay Allochthon. Imbricated within the siliciclastics are thrust slices of Ordovician carbonate. Shallow boulder-strewn bogs and extensive peatbogs characterize the siliciclastic terrane.

The map area is reached via the Viking Highway (Route 73) from Deer Lake to St. Anthony. The highway crosses the map area just north of Hare Bay and provides outcrop and access to the southern part of the area. Farther south,inland areas can be reached on foot from the shores of Hare Bay; areas to the southwest are best reached by air. To the north of the Viking Highway, gravel roads to Cooks Harbour, Boat Harbour and Big Brook allow access to the northern area west of Pistolet Bay. Combined canoe and foot traverse along ponds and winter roads, and use of all-terrain vehicles over some rock barrens, provide access to the area between the gravel road to Big Brook and the Viking Highway.

Previous Work

Ordovician carbonate and clastic rocks of the area were first mentioned by Schuchert and Dunbar (1934) in their stratigraphy of western Newfoundland. Reconnaissance mapping of the Hare Bay area by Cooper (1937) provided the first geologic subdivision of rock units. Cooper also named some of the rock units, including the shaly flysch,which he called the Goose Tickle slate. Tuke (1968) later investigated the stratigraphy, paleontology, deformation and structural setting of the rocks mostly around Pistolet Bay. Tuke's work and the mapping of mining companies were incorporated in a recently published map and memoir by Bostock *et al.*, (1983); no

This project is a contribution to the Canada-Newfoundland Mineral Development Agreement, 1984-1989

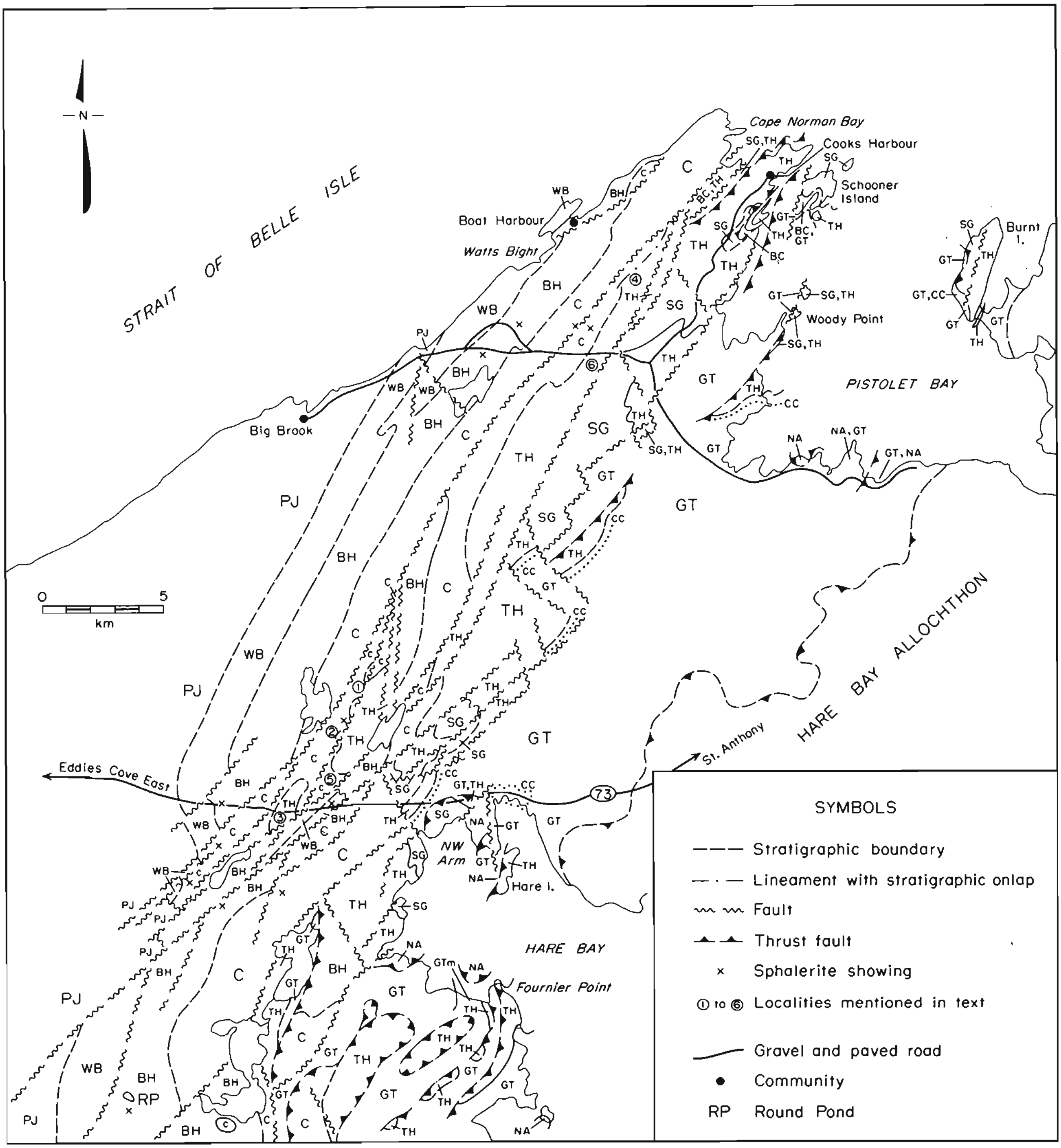

Figure 1: *Geological sketch map of the Pistolet Bay and Hare Bay areas.*

LEGEND

ALLOCHTHONOUS ROCKS

ORDOVICIAN

NA NORTHWEST ARM FORMATION (L. ORD): pyritiferous, green and black shale, gray and black bedded chert, gray limestone including limestone breccia, calcarenite, calcisiltite, thinly bedded ribbon limestone and shale, gray sandstone and locally thick, dark-gray, intraclastic gritty sandstone, and conglomerate.

AUTOCHTHONOUS ROCKS

MIDDLE ORDOVICIAN

GT GOOSE TICKLE FORMATION: dark-gray shale, green-gray sandstone, thinly bedded limestone, slump breccia, shale-pebble conglomerate.

Table Head Group

CC CAPE CORMORANT FORMATION: limestone breccia, calcarenite, and calcisltite.

TH UNDIVIDED TABLE HEAD GROUP: includes Table Point Formation of light-gray to dark-gray, fenestral to thickly bedded, fossiliferous limestone and minor dolostone, and limestone breccia; and Black Cove Formation of black, graptolitic, pyritiferous shale.

LOWER ORDOVICIAN

St. George Group

SG Undivided St. George Group

C CATOCHE FORMATION: undivided; gray limestone, burrowed, cryptalgal mounds, fossilferous; includes overlying thin Aguathuna Formation of yellow weathering dolostone with minor limestone.

BM BOAT HARBOUR FORMATION: interbedded dark to light-gray, dolomitic limestone and buff dolostone, cryptalgal limestone (dolomitization common throughout), widely preserved chert and matrix breccia bodies, especially at base.

WB WATTS BIGHT FORMATION: dark-gray to black, fine to medium grained crystalline dolostone, characterized by light-gray to cream mottling and large cryptalgal mounds.

CAMBRIAN

Port au Port Group

PJ PETIT JARDIN FORMATION: undivided yellow to buff weathering, pale-gray to blue-gray, microcrystalline to finely crystalline dolostone.

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systematic subdivision of the Ordovician carbonates was attempted in that study. Autochthonous Cambrian and Ordovician strata were subdivided in preliminary maps of the Big Brook (12P/9), Eddies Cove (12P/8) and Raleigh (2M/12) map areas by Knight *et al.* (1980) and Knight and Edwards (1978a,b).

The map area contains numerous small sphalerite showings and has been explored by several mining companies. The most extensive work was undertaken by Cominco (Cajka, 1969) who produced a geologic map of the carbonates from Cape Norman to south of Hare Bay. The Ordovician rocks were divided according to lithology, which included several varieties of limestone and dolostone. However, no lithostratigraphic subdivision was attempted. The work of Cominco highlighted mineralization in several areas and led to specific exploration by several companies over the next twenty years (Cominco, 1970; Phillips Management, 1975; Kerr Addison, 1976a,b,c,d,e; Shell Canada, 1975, 1976a,b,c,d,e,f,g; Dean, 1977; Noranda, 1978; John Leslie and Associates, 1980; U.S. Borax, 1980; Essex Minerals, 1981; Narex, 1983).

STRATIGRAPHY

Ordovician Carbonate Rocks

The stratigraphy of Ordovician carbonate strata has been defined in recent years by Knight and James (*in preparation*) and Klappa *et al.* (1980). This framework (Figures 1 and 2) is applied to the carbonates of the map area. The area, however, has a unique character such that several new lithological members have been mapped within the basic formational framework of the St. George (Knight and James, *in preparation*) and Table Head (Klappa *et al.*, 1980) groups.

St. George Group. The St. George Group comprises limestone, dolomitic limestone and syngenetic and secondary dolostone. It is approximately 395 m thick and includes the Watts Bight, Boat Harbour, Catoche and Aguathuna formations.

Watts Bight Formation

The Watts Bight Formation consists of a 90 m thick section of blocky to friable, tan-gray weathering, dark gray and black, fine and medium grained, crystalline dolostone. The dolostones have replaced dominantly subtidal, burrowed and cryptalgal limestone. Original textures are revealed by a characteristic light-gray to white fabric-selective mottling. Large stromatolite and thrombolite mounds, burrowed carbonate, cross-bedded grainstones and minor laminated dolostone occur. There are many cavities 1 to 10 cm in diameter within the formation, many of them partly filled by black and pinkish-buff, geopetal dolomite and dolomite mudstone. The formation has a sharp conformable contact with underlying, white, light-gray and gray, microcrystalline to finely crystalline dolostones of the Petit Jardin Formation.

Boat Harbour Formation

The Boat Harbour Formation, in contrast, comprises an approximately 120 m thick section of cyclically alternating limestone, dolomitic limestone and dolostone, and lies conformably upon the Watts Bight Formation. The basal unit consists of yellow weathering, thinly bedded, laminated and mottled, dark-gray to light gray, fine grained dolostones. Common within this unit, and locally straddling the basal contact, are breccia pods containing a dolostone-chert matrix. The breccias are up to tens of metres in size, consisting of angular fragments (approximately 1 cm across) of the host rock dolostones set in a fine grained matrix of siliceous dolomite. Fracture breccias and veins, cemented by white dolomite spar, commonly occur in the dolostones above and around the matrix breccia.

Silicification of the rocks in the basal interval is widespread. Chert has selectively replaced stromatolites, cryptalgal laminite, mudcracked laminated carbonate, and clasts of rip-up intraformational conglomerate. Lumps of white chert and concentrically layered chert concretions also occur. Lithoclasts of the cherts are incorporated in the matrix breccias suggesting it has either an early syndepositional or postdepositional origin. Poor exposure of the contact between the breccias and the host rocks makes interpretation of the breccias difficult. In some coastal and quarry exposures, however, the breccias involve thrombolitic dolostone beds of

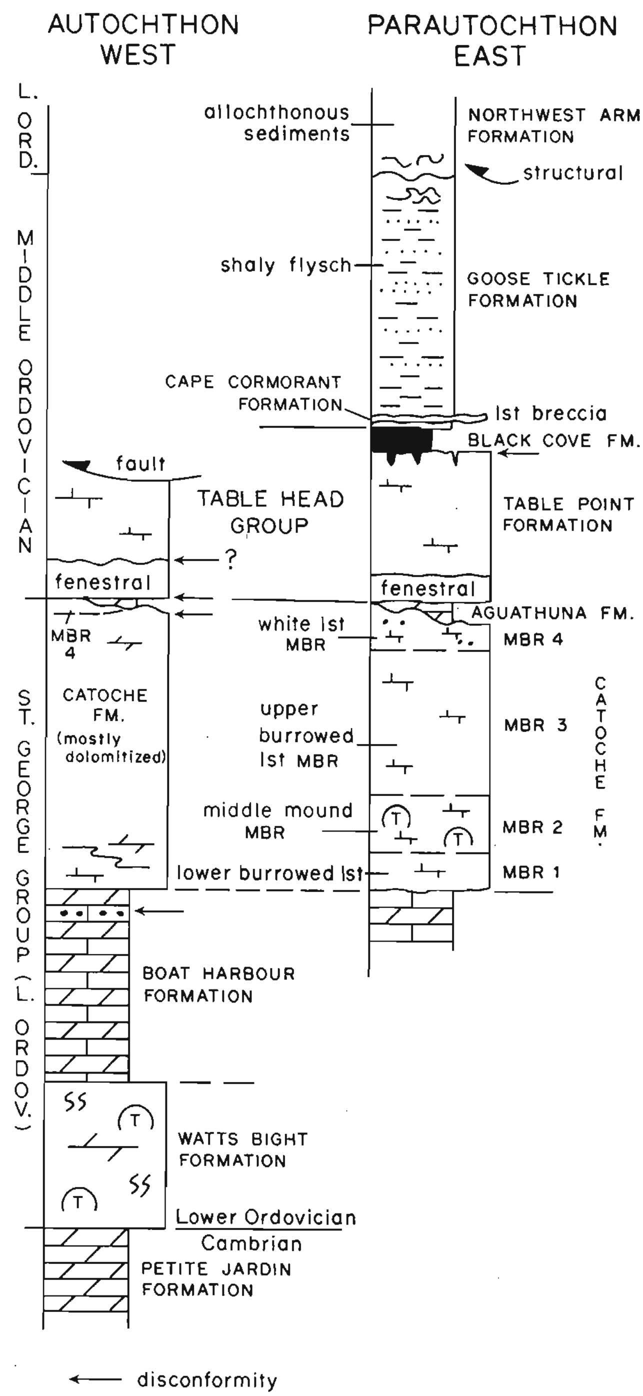

Figure 2: *Stratigraphy of Ordovician rocks of the Pistolet Bay-Hare Bay area.*

the underlying Watts Bight Formation and are commonly accompanied by a system of fractures. Dolostone beds, as they enter the breccia toward its base, have been warped downward, suggesting material was removed from underneath; the beds are broken in the breccia. Within the breccia proper, large blocks up to 1 m across have a vague imbricated stacking above a finer breccia at the base. There is a crude lithological stratigraphy of the blocks within the breccia at Boat Head. The lower parts of the breccia have a matrix of smaller dolomite - chert clasts and sand. However, the top of the breccia at Boat Head is spar cemented beneath fractured but bedded dolostones. In quarry exposures on the Viking Highway, the matrices of breccia pockets in Watts Bight dolomites are partially replaced by coarse grained dolomite. Pyrite and less commonly sphalerite and galena also occur in the breccias.

Above the basal dolostone-breccia interval, the formation consists of metre thick sequences of burrowed, fossiliferous, dark-gray limestone, wavy, flaser, and thinly bedded dolomitic limestone and mudcracked dololaminite and laminated dolomitic limestone. Stromatolitic and thrombolitic limestone occur in some of the sequences, which are typical of shallow peritidal settings, especially muddy tidal flats.

Approximately 12 m from the top of the Boat Harbour Formation, there is a disconformity. It is characterized by a thin pebble bed of white and dark-gray chert pebbles in light-gray dolostone at Boat Harbour and on the gravel road to Big Brook. In frost-shattered outcrops north and south of the Viking Highway, it is characterized by conglomerate and pebbly dolostone. The conglomerates are up to 25 cm thick, consist of pebbles 1 to 3 cm across, angular, white cauliflower and gray chert pebbles mixed with subrounded to rounded, massive to laminated, dolostone pebbles. Crude planar stratification and grading occur in the conglomerate. The variable thickness of the conglomerate suggests it lies above an erosion surface, although this has not been confirmed.

Above the disconformity, the Boat Harbour Formation continues to exhibit cyclic sequences of very fossiliferous, grainy limestone, burrowed limestone, and flaser bedded, laminated, mudcracked limestone and dolostone. Rare mound beds of cryptalgal thrombolite occur locally.

Dolomitization that is both pervasive and bed selective replaces limestone, resulting in mottled dolostone, vuggy dolomite pseudobreccia and salt and pepper dolomites.

Catoche Formation

The Catoche Formation is a 170 m thick succession of subtidal dark-gray and white limestone. The carbonates, in undolomitized parautochthonous eastern strata, consist of burrowed fossil-rich limestones, sponge-thrombolite mounds, grainy limestones, white peloidal grainstones, and fenestral limestones. In autochthonous western sections, near Cape Norman and southward to the Viking Highway, this same section is extensively dolomitized to dark-gray, massive, crystalline dolostone and pseudobreccia.

Four lithologic members are divisible in the formation on Schooner Island: 1) a lower burrowed limestone member, 2) a middle mound member, 3) an upper burrowed limestone member, and 4) a white limestone member. The lower burrowed limestone member is 18 m thick and consists of gray, unevenly thin bedded limestones. The limestones consist of burrowed fossiliferous mudstone containing many lenses and thin beds of intraclastic and bioclastic grainstone and rudstone. Some cryptalgal mound beds also occur. The overlying middle mound member is 34 m thick and consists of very large, massive mound complexes composed of cryptalgal thrombolites and scattered sponges. Host to numerous large shelly organisms and possessing evidence of marine cementation, the high-energy mound complexes are surrounded by grainstone fringes and channel fills. Above the middle mound member, dark-gray, massively bedded, burrowed limestones begin the upper burrowed limestone member. These rock types continue through the 105 m thickness of the upper burrowed limestone member, intercalated with cross-laminated and wavy thin bedded grainstones. Some thrombolite mound beds occur sporadically. The limestones have considerably less fossils than the lower member although silicified cephalopods, gastropods and rostroconchs do occur.

The Cathoche Formation is capped by a 13 to 16m thick member of white limestone. The member includes stylolitic, peloidal grainstones, massive, mottled, thrombolitic boundstones and beds of fenestral white limestone. Large shelly fossils occur sporadically in the member and include trilobites suggestive of Ross-Hintze trilobite Zones H to I (Boyce, *this volume*). This member is well exposed on Schooner Island and Burnt Island and in folded sections along the shores of Hare Bay. Roadside outcrops of the member also occur along the Viking Highway near the new St. Anthony airport and at the airport itself. The member outcrops discontinuously in autochthonous, gently dipping strata in the western part of the map area. In some instances, it appears to be crosscut erosively by the overlying Aguathuna Formation, e.g., localities 1, 2 and 3 on Figure 1. At locality 5 (Figure 1), there is no evidence that the member occurs beneath the Aguathuna Formation, which rests upon dark-gray, secondary dolostones typical of those that replace the upper burrowed limestone member. Honey-colored weathering, light-gray pseudobreccias and secondary dolostones replace the white limestone member, making distinction between members possible where the succession is extensively dolomitized.

Aguathuna Formation

The Aguathuna Formation is mapped for the first time in the area. In sections on Schooner Island and the shoreline of Hare Bay, it is between 7 and 16 m thickness. Rocks typical of the formation are absent on Burnt Island, where an erosional disconformity separates overlying rocks assigned to the Table Head Group from the white limestone member of the Catoche Formation. A finely laminated dolostone and dolomitic limestone bed, 60 to 210 cm thick, overlies the erosional surface and may be the only strata that belong to the Aguathuna Formation (see later discussion of disconformity). However, the laminite also closely resembles basal beds in the Table Point Formation elsewhere in the area.

The Aguathuna Formation on Schooner Island, Hare Bay, and in some sections on the southwest side of Pistolet Bay, predominantly consist of 1.5 to 7.5 m thick units of medium bedded, pale-gray, microcrystalline dolostone, intercalated with two or three beds, 40 to 100 cm thick, of pale-gray to white limestone. The limestones are cryptalgal laminites and stromatolites composed of laterally linked hemispheroids. Burrow-mottled limestone locally occurs near the base of the formation where it is intercalated with the dolostones. Sedimentary structures in the dolostones include planar to undulose, thin stratification and lamination, cross-lamination, shallow scours, desiccation cracks, disrupted lamination, and white chert cauliflower nodules. These structures and rock types support a restricted intertidal-supratidal origin for the formation.

Table Head Group. Limestones of the Table Point Formation, black shales of the Black Cove Formation and pebbly mudstone and calcarenite of the Cape Cormorant Formation define the Table Head Group in the map area. No Table Cove Formation (see Klappa *et al.*, 1980) occurs.

Table Point Formation

The Table Point Formation is about 80 m thick and consists of dark-gray to light-gray limestone, minor dolomitic limestone and a variety of dolostones. The widest range of rock types occurs in the first 25 m of the formation where three lithological associations are defined. Directly overlying the Aguathuna Formation, rock types range from basal limestone-dolostone conglomerates, through nodular, thin bedded, argillaceous, fossiliferous, limestones, to dolomitic limestones and dololaminites. The dolomitic limestones and dololaminates are flaser bedded, cross-laminated, laminated and mudcracked. This association, which can be up to 2.2 m thick, is best seen in the area of Schooner Island and southwestward from Cooks Harbour to the new St. Anthony airport. The basal conglomerate on Schooner Island is composed of large platy dolostone clasts up to 12 by 2 cm in size, mixed with smaller pebble and sand-sized dolostone grains and pebbles of white quartz. The Aguathuna dolostones are locally brecciated and penetrated by fractures filled with sandy dolomitic limestone for up to 20 cm below the Table Point Formation. Conglomerate beds higher in the lithological association fill channels that cut into nodular thin bedded limestones. Thin lenses of laminated lime mudstone occur in the conglomerates. Conglomerates are absent in the Hare Bay sections where laminated and flaser bedded dolostone and dolomitic limestones lie sharply upon the Aguathuna Formation.

The second lithological association overlies the thin basal association on Schooner Island. It also occurs in the core of a tight anticline just north of the fish plant at Cooks Harbour, and outcrops at the new St. Anthony airport. It consists of thick units of gray, nodular, thin bedded, argillaceous limestone, containing intercalated beds of skeletal packstone, grainstone and coquina limestone, parted dolomitic limestone and beds of mixed grainy and parted limestone. The coquinas are rich in brachiopods. At the top of the sequence, a bafflestone bed, 1.2 m thick, contains stick sponges in a wackestone matrix.

The third lithological association is delineated on Burnt Island and in the most westward outcrops of the Table Point Formation near the Big Brook road (locality 6, Figure 1), and in outliers north of the Viking Highway (localities 3 and 5, Figure 1). This association consists of thick beds of nodular, thin bedded, dark-gray limestone and of light-gray, fine grained limestone. Typically, the fine grained, light-gray limestone beds consist of fossiliferous limestones rich in large gastropods and cephalopods that are replaced by calcite spar. Large burrows and large 'stromatactoid' cavities are also spar cemented. The tops of beds are rich in layers of fine tubular and laminar fenestra, and are faintly laminated. They commonly contain ostracodes, and mudcracks occur at the top of some beds. Oncolites, coated grains, intraclasts and bioclasts occur in grainy layers in the nodular limestones.

An impressive, irregular, downcutting erosion surface (Figure 3) occurs in the fenestral limestone facies in a roadcut and quarry on the Viking Highway (locality 3, Figure 1). Locally, conglomerate lags occur at the base of the channel and limestones are locally dolomitized to yellow weathering, microcrystalline dolostone beneath the erosion surface.

The remaining 50 m of the Table Point Formation consist of dark blue-gray, seamy, argillaceous limestones. They characteristically consist of thick beds of burrowed, fossiliferous wackestone-packstone. Rare beds of peloidal grainstone and chert layers also occur. Where the top of the formation escaped erosion, the limestone consists of crinoid-trilobite-brachiopod-rich grainstone and packstone. These grainy beds are present on Schooner Island and in thrust slices of the formation at Shallow Bay, Pistolet Bay. They are missing and believed eroded in outcrops on the east side of Woody Point, on Burnt Island, and on Hare Island, Hare Bay. In each case, the top of the limestone is cemented by a carbonate-silica crust, 2 to 3 cm thick. On the south side of Burnt Island, the top is hummocky, and cut by fractures and faults with small displacements. The surface, including the fractures and fault planes, is impregnated by the crust. The top of the limestone is everywhere overlain by black shales assigned to the Black Cove Formation.

Black Cove Formation

The Black Cove Formation is 7 to 8 m thick. It consists of finely laminated, pyritiferous, graptolitic, black shale. Pyritic laminations and light-gray concretionary limestones occur in the formation. The Black Cove Formation lies sharply upon the Table Point Formation, and in some outcrops it infills long narrow fissures that penetrate tens of centimetres down into the underlying Table Point Formation. The shale also overlies the eroded top of the Table Point Formation at Burnt Island, although here it is only 1.8 m thick.

In Cailloux Bay and Vaches Point, Cape Norman Bay, the black shales are intercalated stratigraphically with three units of matrix-poor limestone breccia. The shales form units 4 to 14 m thick and the limestone breccia units are 5 to 19 m thick, in a section at least 60 m thick. The breccias are composed of black wackestone fragments, 1 to 10 cm across, of the Table Point Formation, as well as fragments of white sponge, white crinoid-trilobite grainstone (probably from the top of the Table Point Formation), platy lime mudstone lithoclasts and irregular shale rip-ups. The main lithoclasts fit neatly together with only a hairline of shale matrix in between. Similar limestone breccias overlain by shale of the Black Cove Formation occur in structurally complicated areas of Pistolet Bay and Hare Bay. In none of these instances are the shales repeatedly intercalated with limestone breccias as at Cape Norman Bay. At Cape Norman Bay, however, contacts between breccias and overlying shales are not exposed and it is impossible to know if the two rock types are structurally intercalated. A number of lines of evidence, however, suggest that the upper contacts are stratigraphic. Firstly, the thicknesses of the breccias are markedly different. Secondly, the abundance of non-wackestone clasts differs from breccia to breccia. These two properties suggest that the breccias are separate units. In addition, where thrust contacts have been mapped in the area, limestones are always thrust over Black Cove black shales, and not vice versa. However, basal contacts of the limestone breccias with the shales at Cape Norman Bay are stratigraphic.

An unexposed area conceals approximately 35 m of strata above the last breccia. The covered interval ends at Vaches Point where shales and thin bedded sandstones and limestones typical of the base of the Goose Tickle Formation are overlain along a structurally modified contact by a further limestone breccia several metres thick. Unlike the lower breccias, it contains blocks of Table Point limestone up to several metres across within the finer lime breccia. The breccia appears to pass eastward beneath unbrecciated Table Point limestone (Sheila Stenzel, personal communication, 1985). These enigmatic limestone breccias are not included here with limestone pebbly mudstones and calcarenites that are assigned to the Cape Cormorant Formation.

Cape Cormorant Formation

The Cape Cormorant Formation is a thin, distinct unit composed of matrix-supported pebbly mudstone at the base, and granular to very fine grained calcarenites and calcisiltites at the top. The formation is variably developed and consists only of the calcarenite bed in some sections, e.g., Schooner Island and parts of Burnt Island. In roadcuts on the Viking Highway and coastal exposures near Northern Arm, Hare Bay, the pebbly mudstone is possibly up to 6 m thick. In thrust slices on the east side of Woody Point, Pistolet Bay, it is 0.95 to 2 m thick.

The pebbly mudstone consists of irregular, knobbly lithoclasts 1 to 6 cm across, of Table Point limestone and 10 cm to 1 m wide blocks of Table Point limestone, Black Cove shale, platy lime mudstone, thin bedded limestone, grainstone, and dolomitic calcareous siltstone and sandstone, all set in a shaly matrix. Sandstone rip-ups from the underlying beds are incorporated in the pebbly mudstone at roadcut exposures on the Viking Highway. In Pistolet Bay, the bed has a well developed stylolitic cleavage which surrounds the lithoclasts; some platy clasts are rotated into the plane of the cleavage.

A bed of graded calcarenite up to 75 cm thick lies above the pebbly mudstone. It is the most widespread unit of the formation and is locally only 30 cm thick. A normally graded bed, it is composed of grit or very coarse grained calcarenite at the base and very fine grained lime sand at the top. The bed consists of a massive basal interval, overlain by laminated, and cross-laminated intervals, both of which are commonly convoluted. The top of the Cape Cormorant Formation is marked by a 30 to 65 cm thick bed of light-gray calcisiltite. Internally, the bed is highly convoluted although originally it may have been cross-laminated.

Klappa *et al.* (1980) defined the Cape Cormorant Formation as a sequence of dark-gray to black calcareous shales and green siltstones, with interbedded calciturbidites and limestone breccia-conglomerates that lay between Black Cove shales and green sandstones similar to those of the Goose Tickle Formation. In the map area, sandstones and shales lithologically similar to those of the Goose Tickle Formation lie between the Black Cove shale and the base of the Cape Cormorant limestone breccias and calcarenites. At North Arm, Hare Bay, there are at least 5 m of sandstones beneath the Cape Cormorant Formation and in the Pistolet Bay area 50 to 100 cm of Goose Tickle type siliciclastics are sandwiched between the Cape Cormorant Formation and the Black Cove shales. Positional problems such as this, together with the absence of the Table Cove Formation in this area and the clearly disconformable top to the Table Point limestones, suggest that the Black Cove and Cape Cormorant formations would be best considered outside the Table Head Group.

Ordovician Siliciclastic Rocks

This grouping of rock units includes autochthonous Middle Ordovician shaly-sandy flysch of the Goose Tickle Formation and allochthonous melange-like strata of the Lower Ordovician Northern Arm Formation.

Goose Tickle Formation

The Goose Tickle Formation is a highly folded succession of gray to black, locally graptolitic, shales, sandstones and lesser thin calcareous beds. The sandstone beds are mostly 5 to 20 cm thick and fine to very fine grained. They are typified by laminated B, and cross-laminated and ripple drift C Bouma divisions. Thin, very coarse to coarse grained sandstones occur at the base of some beds. Convolution and overturning of cross-lamination is common with structures facing to the south, Fluted and loaded bases are also common. Paleoflow directions are consistently directed to the south.

The formation is finer grained in the Hare Bay area, where it has a strong slaty cleavage. Several metre-thick units of intraformational breccia, composed of deformed lithoclasts of Goose Tickle mudstone and fine grained sandstone, are interbedded stratigraphically high in the formation in the vicinity of Goose Tickle, Hare Bay. Basal contacts are transgressive and erosive. However, upper contacts are not sufficiently exposed to indicate if the breccia formed as discrete episodes of slumping or as intraformational slides related to emplacement of the Taconic sedimentary rocks of the Hare Bay Allochthon.

Immediately below the allochthonous Northwest Arm Formation, the Goose Tickle Formation is strongly flattened. In this flattened zone, which presumably involves only the youngest beds of the formation, there are some intraclastic grits and conglomerates. They range from a few centimetres to 25 cm thick, are interbedded with shales and thin sandstones, and contain green and black shale intraclasts. These intraclasts were interpreted by Williams and Smyth (*in* Bostock *et al.*, 1983), to have been derived by erosion of Northwest Arm Formation shales.

The Northwest Arm Formation is a mélange-like deposit composed of interlayered black and green, pyritiferous shale containing suspended dismembered beds and sequences of various other rock types. These include gray, green and black, bedded cherts, light-gray ribbon limestones and shales, granular to sandy calcarenites displaying Bouma sequences, thin, cross-laminated and laminated, calcareous siltstones and fine sandstones, and thick green-gray gritty sandstones. Red siltstone blocks occur in the formation on the west side of Hare Island.

EVOLUTION OF ORDOVICIAN PLATFORM

Disconformities, Growth Faults and Breccias

Discussion. Variations in limestone successions laid down on carbonate platforms are the response to fluctuations of relative sea level rise and fall (James, 1984). During prolonged periods of relative sea level rise, shallow-shelf seas transgress onto the platform and lead to widespread deposition of dominantly subtidal carbonate. During relative sea level fall, the shallow seas are overwhelmed by production of carbonate sediment and peritidal sediments are widely deposited. Regional subaerial exposure leading to karstification of the platform carbonates may mark the end of this fall in sea level.

In western Newfoundland, the St. George Group consists of two megacycles that contain a history of subtidal to peritidal sedimentation and eventual subaerial exposure (Knight, 1980, 1985; Knight and James, *in preparation*). The two megacycles involve Tremadoc and Arenig strata. The older disconformity, represented by the Boat Harbour 'pebble bed', terminates the Tremadoc cycle. A relatively obscure feature, it is known to coincide with the absence of Ross-Hintze trilobite Zone G (Boyce, 1983) and faunal changes in both conodonts (Stouge, 1982) and trilobites (Boyce, 1983).

Evidence for the closing history of the later Arenig cycle is more spectacular. Previously, evidence for an interval of subaerial exposure at the top of the St. George Group in the map area was confined to knowledge of an erosion surface between the St. George and Table Head Groups on Burnt Island (Cumming, *in* Bostock *et al.*, 1983). However, there is new evidence in the map area of not only multiple breaks during this period, but also of active faulting affecting the Ordovician platform. Three erosional surfaces occur:

1) *at the base of the Aguathuna Formation.* The evidence for this break includes: a) erosion of the white limestone member of the Catoche Formation below the Aguathuna Formation dolostone at localities 1,2,3, and 5, Figure 1; b) dolostone-filled fractures and breccias in the underlying white limestones in sections at Hare Bay and the east side of Woody Point, Pistolet Bay. Similar fractures and porosity occur in the white limestones beneath the disconformity on Burnt Island. A fracture cutting third member limestones of the Catoche Formation is cemented by chert in the section in Hare Bay; c) onlap of a northeast-trending lineament by gently eastward-dipping Aguathuna and Table Point formations at locality 4, Figure 1. Brecciated, cavernous and silicified, dark-gray dolostones that replace limestones of the Catoche Formation lie against the lineament to the northwest. The Catoche Formation strata are locally folded at the southwest end of the lineament, where they appear to be unconformably overlain by the Aguathuna Formation.

A number of lines of evidence suggest the lineament is a late Arenig feature rather than a later fault. Firstly, later faults that cut Ordovician carbonates are usually typified by closely spaced joints that parallel the fault plane. This feature does not occur in strata adjacent to the lineament. Also, strata of the Aguathuna and Table Head formations show no sign of buckling, as might be expected if they were affected by later faulting. Secondly, the lineament cannot be traced southwestward into a succession that is apparently conformable through the Catoche Formation into the Table Head Group. To the northeast, the lineament is cut out by later faults that have a north to northeast trend. Lastly, at one locality, a tongue of frost-shattered syngenetic dolostone, similar to dolostones of the Aguathuna and basal Table Point formations, oversteps the lineament onto the Catoche dolostones. Cavity porosity in the Catoche dolostone at the margins of the tongue are infilled by the younger dolostone. This suggests that the frost-shattered dolostones are essentially in place (not the product of Quaternary marine or glacial transportation) and that they infilled a shallow trough in the Catoche dolostones. The onlap implies subaerial exposure of the Catoche Formation and the lineament.

2) *at the base of the Table Point Formation.* Evidence for a disconformity at this contact is suggested by: a) basal conglomerates composed of dolostone pebbles at the base of the Table Point Formation on Schooner Island and south of Cooks Harbour. No conglomerate occurs in the Hare Bay sections, where Aguathuna dolostones are abruptly overlain by laminated limestones of the Table Point formation; b) limestone and rubble-filled fractures that penetrate as much as 20 cm down into the top of the Aguathuna Formation at several localities; c) the presence of a marked erosion surface and the absence of Aguathuna dolostone at Burnt Island. Here the Table Point Formation lies directly upon white limestone of the Catoche Formation. Secondary porosity and narrow fissures, both filled by dolomite mudstone penetrate the white limestones for several metres below the disconformity. The disconformity is overlain by laminated dolostone and limestone assigned to the Table Point Formation.

3) *within the fenestral limestone association of the basal Table Point Formation.* A well exposed surface of erosion (illustrated in Figure 3) with relief of 2 to 3 m occurs in a roadcut and quarry on the Viking Highway (locality 3, Figure 1). Macrofossils above and below the surface are the same (Boyce, personal communication, 1985), suggesting no significant length of geologic time is represented. However, pebbles of limestone and dolostone with spar-cemented fenestra occur in the overlying limestones, suggesting that the underlying carbonates were already lithified. Beds below the erosion surface were also slightly tilted.

Bodies of matrix and spar breccia occur regionally in the basal part of the Boat Harbour Formation. They also straddle the contact between the Watts Bight and Boat Harbour formation.

Interpretation. Two distinct episodes of subaerial exposure affected the Ordovician platform. Both terminated a time of regression on the platform when relative sea level fell and shallow-water peritidal carbonates were exposed and subjected to diagenesis, dissolution and erosion (Knight and

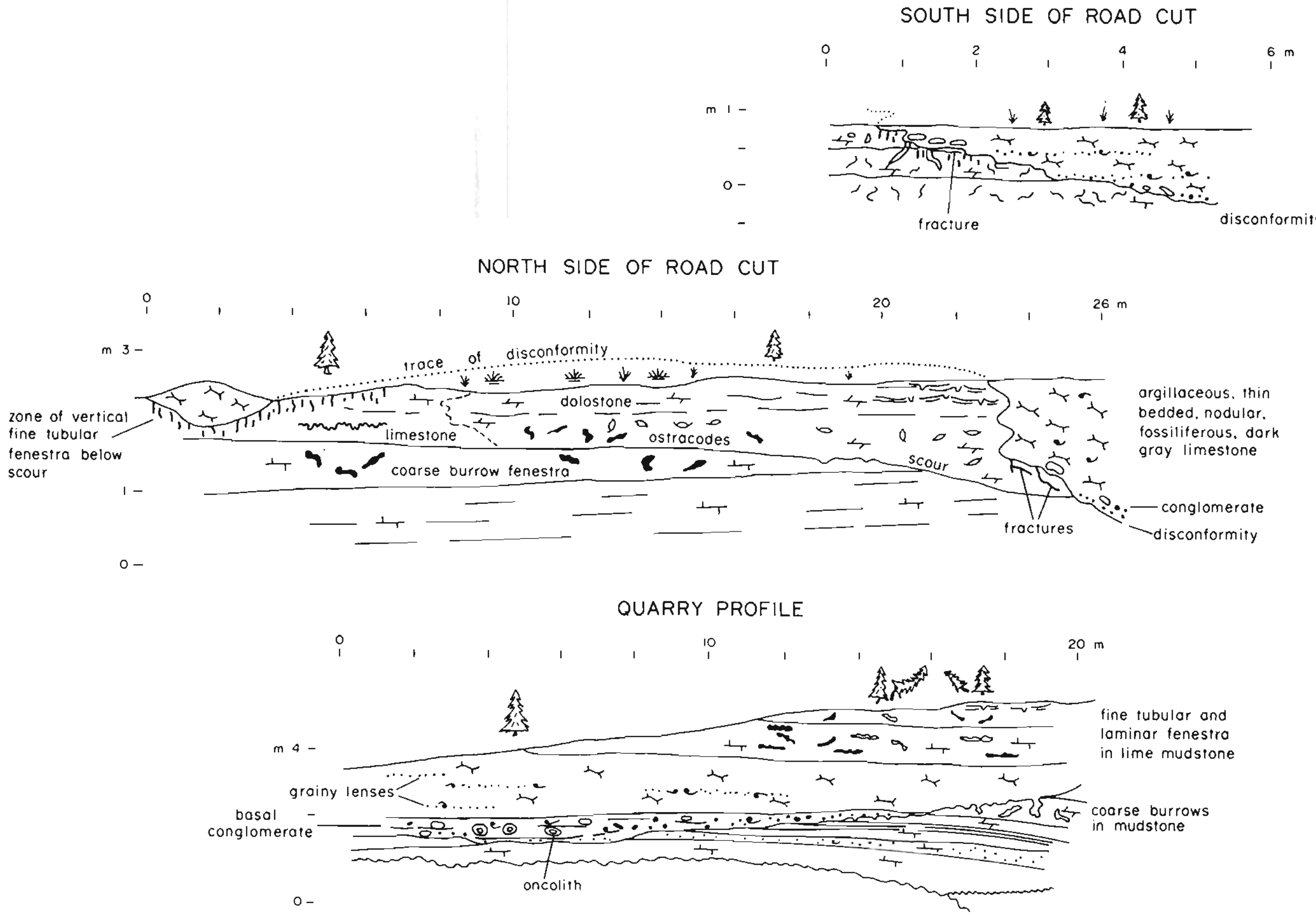

Figure 3: *Field sketches of disconformity surface in basal strata of the Table Head Group, Viking Highway (localtiy 3, Figure 1).*

James, *in preparation*). There is, however, a marked contrast between the Tremadoc and later Arenig event. The older event developed upon a relatively stable platform such that thickness and patterns of lithofacies above the Boat Harbour disconformity are relatively consistent throughout western Newfoundland. Physical evidence of the karst is limited to thin pebble lags and chert conglomerates associated with dolomitization, silicification and dissolution. The break is supported by faunal evidence.

The younger event is clearly much more complex. At the end of the Arenig, western Newfoundland was under tectonic stress, and faults broke through the platformal cover (see Knight, 1985, page 84; Knight and Boyce, 1984). The onlap of the lineament by both the Aguathuna and Table Point formations suggest that the faults penetrated the carbonates toward the end of the Arenig, after white limestones of the Catoche Formation containing Ross-Hintze Zone H to I trilobites were deposited. Because the lineament follows the trend of and lies between braids of the Ten Mile Lake Fault system, it is interesting to speculate that it may preserve evidence of Arenig movement upon the fault. Outliers of the Table Head and Aguathuna formations near the Viking Highway are preserved within a narrow zone of faults that are part of the Ten Mile Lake Fault system. Unconformable relationships of these rock units mapped in this fault zone may also reflect Arenig instability above the Ten Mile Lake Fault. On a regional scale, the faulting uplifted the Catoche carbonates- the subsequent erosion may be reflected in the unconformities on Burnt Island and locally in the Ten Mile Lake Fault system. Widely developed, brittle rock fractures and secondary solution porosity was later filled by Aguathuna dolostone. Dolomitization of extensive areas of the Catoche Formation to the west of the Ten Mile Lake Fault system occurred during this period of uplift. This is supported by the tongue of younger dolostones that oversteps both the lineament and Catoche Formation dolostones (locality 4, Figure 1), indicating subaerial exposure of the dolostones.

The marine waters that gently flooded this uneven platform surface were (or became) saline. Dolostones and laminated cryptalgal limestones of the Aguathuna Formation were deposited in tidal flats and possibly saline ponds and lagoons that merged about topographic islands.

A marked lithological change between the Aguathuna and Table Point formations, and brittle fracturing and erosion of the Aguathuna dolostones, suggests an erosional disconformity at the upper contact of the St. George Group. Of unknown magnitude, this event was followed by Middle Ordovician transgression. Fenestral limestones interbedded with fossiliferous burrowed limestone suggest prograding peritidal

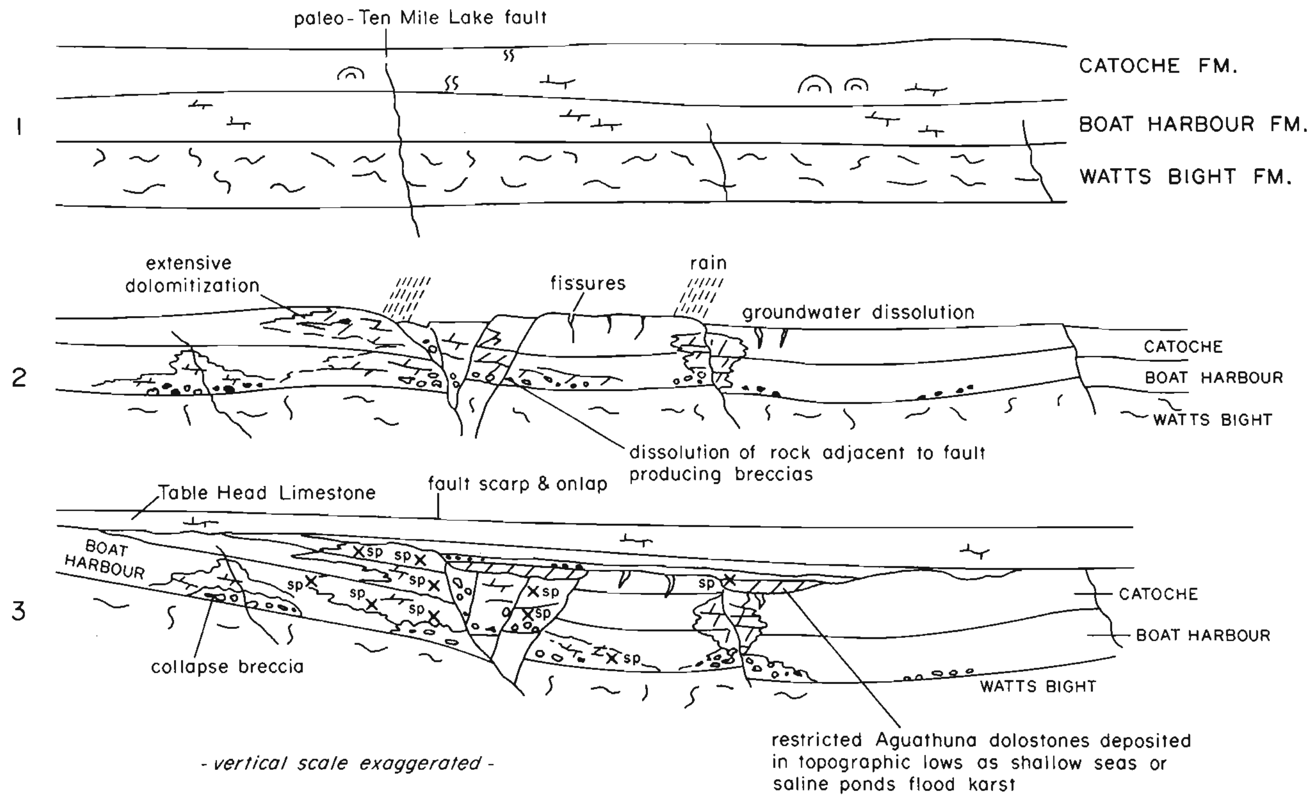

Figure 4: *A simplified model of Ordovician platform history in the Pistolet Bay-Hare Bay area.*

1. *Buildup of stable platform throughout the Early Ordovician.*
2. *Late Arenig faulting coinciding with regional regression and subaerial exposure of the platform.*
3. *Erosion and karstification, followed by deposition of restricted lithofacies in lows on karst surface before later widespread Middle-Ordovician transgression. The platform was block faulted during Appalacian orogenesis with Ten Mile Lake Fault widely penetrating the platform in a system of new and reactivated splays.*

sedimentation accompanied by rapid lithification and freshwater diagenesis and cementation. This erosional surface suggests an interval of subaerial exposure during the early Llanvirn transgression. Tilting of beds prior to erosion indicates that some tectonism affected the platform during this interval.

The matrix and spar breccias that are discordant to bedding and are regionally associated with the lower strata of the Boat Harbour Formation are probably cavern breccias. Large open spaces created by dissolution were filled by overhead and marginal collapse. A crude stratigraphy of blocks, upward increase in block size in some breccias, and a pebble to silt size dolomite-chert matrix at the bottom of the breccias support the idea of caverns. Open spaces that remained at the top of the breccias, and in fractures that opened in overlying dolostones as they settled onto the breccias, were cemented by white baroque dolomite.

The primary control of these breccias is still unresolved. There is no evidence that the St. George Group contained significant bedded evaporites. Evaporitic cherts do occur and the silicification of algal mats in the basal Boat Harbour Formation may possibly reflect an evaporitic sabhka as seen in similar Ordovician ribbon cherts of the Aleman Formation, southwestern New Mexico (Geeslin and Chafetz, 1982). In other areas of the Northern Peninsula, it is dolomitized limestone beds which pass laterally into the matrix breccias (Knight, *in preparation*).

Located approximately 100 m stratigraphy below the Boat Harbour 'pebble bed', the cavern breccia and sediment-filled secondary porosity in the underlying Watts Bight Formation may be related to the episode of subaerial exposure that marked the close of the Tremadocian history of the platform. An alternative explanation would relate the breccias to the later Arenig episode of faulting and subaerial exposure. Block faulting of the platform during the Arenig event may have provided structural permeability for the movement of groundwaters and other fluids during and after the episode of subaerial exposure. In the map area, matrix breccias, extensive areas of dolomitization and minor metallic mineralization occur close to faults, especially the Ten Mile Lake Fault system (Figure 4), indicating fluid migration. The Boat Harbour matrix breccias are spatially related to major faults in other areas of the Northern Peninsula (Knight, 1985).

History of Platform Collapse

Tuke (1966), observing the sharp contact of Black Cove shale (he placed it in the Goose Tickle Formation) upon Table Point limestones, and the shale-filled fissure beneath this contact, suggested a disconformity at this boundary. The absence of the Table Cove Formation (Klappa *et al.*, 1980) between the limestone and the shale supports this idea. In addition, widespread evidence of deformation and erosion of the Table Point limestone and the early submarine(?) cementation of the eroded top of the limestone suggest a complex end to platform development.

In the siliciclastic sequence, the Black Cove shale is overlain by Goose Tickle Formation flysch in the Schooner Island section; the top of the Table Point Formation is a bioclastic grainstone-packstone. In other sections, the shales are interbedded with limestone breccias derived from Table Point limestone. Elsewhere, a thin unit of limestone, pebbly mudstone and lime turbidite overlie the black shale and are intercalated in the basal beds of the Goose Tickle Formation. The top of the Table Point limestone is generally cemented and/or eroded beneath the pebbly mudstone.

A sequence of events can be tentatively suggested based upon the above features. The last deposits of the Table Point Formation appear to consist of bioclastic grainstones and packstones. Limestone sedimentation ceased and the later development of fissures, as well as retention of the nodular form of limestone clasts in overlying breccias, suggests the Table Point Formation was at least partly lithified during an interval of nondeposition. The absence of Table Cove Formation suggests a slope did not develop in this area, the platform rapidly collapsed, and the shales were deposited on the drowned shelf. Tectonism probably created the fissures prior to deposition of the black shales in a basin or basins of restricted circulation (Klappa *et al.*, 1980).

In some areas of the basin, Table Point limestone was uplifted along faults and matrix-poor limestone breccias were deposited as a series of thick sheets or wedges. These massive breccias sit with sharp contacts within the shales and in basal beds of the Goose Tickle flysch. The apparent lack of erosion at the base is puzzling for such massive deposits. However, the upper most breccia at Cape Norman Bay appears to pass laterally into unbrecciated Table Point limestone. This may suggest that these limestone breccias formed essentially in place at the foot of steep, fault-controlled scarps that were repeatedly active during the early history of the shale basin.

In the east of the basin, Table Point limestone was uplifted together with the Black Cove shales. Probably weakened by tectonic instability and perhaps tilted at fairly steep angles, large masses of limestone and shale slumped off the highs to disintegrate into widely distributed debris flows of the Cape Cormorant Formation. Elevated tectonic islands of eroded Table Point limestone left stranded above the sea floor were frequently cemented by silica and dolomite. This cement either developed as a deep-water submarine hardground or it formed later and diagenetically at the shale-limestone contact since thin measures of Black Cove shale overlie the eroded and cemented crust at Burnt Island. Here, there are also thin beds of Cape Cormorant Formation within the basal part of the Goose Tickle flysch; this suggests there were repeated pulses of uplift and erosion. Uplift, erosion and deposition of thin debris flows indeed continued as sandy flysch of the Goose Tickle began to flood southward along the basin. The presence in some of the thicker breccias of tabular bedded limestone lithoclasts, similar to slope limestones of the Table Cove Formation of Klappa *et al.* (1980), suggests uplift of a Table Head Group section outside the map area.

A long narrow slice of Table Point limestone and black shales that occurs in the structurally complex rocks of the east side of Woody Point may have been detached from its parent and transported into the shale basin as an olistolith. Where hard-rock thrusts of limestone on shale are observed, there are always zones of intense shearing at the base of the limestones. However, in the narrow slice discussed here, the base is not sheared but it is uneven and lumpy, suggesting that lumps of limestones have been plucked from it along an uneven surface. Also, the underlying sediments of the basal Goose Tickle Formation are not sheared although they are overturned. Drag folds in the Goose Tickle immediately below the 'olistolith' indicate that it slid into place from the west. The western margin of the olistolith is nearly vertical and are locally cemented by a chert-dolomite crust. Nearby on the same margin the limestone has broken down into a pocket of lumpy breccia with shale incorporated around the limestone lumps. All these features are indicative of early postdepositional processes and support an 'olistolith' origin for the limestone wedge.

STRUCTURE

The map area contains three contrasting structural terranes. The first, in the west, consists of gently eastward-dipping autochthonous carbonates. The most conspicuous structures are steep, north to northeast-trending faults.

The second terrane, east of the carbonates is generally bordered on the west by a splay fault of the Ten Mile Lake Fault, and on the east by the Ordovician siliciclastic terrane. In the second structural terrane, some carbonates are clearly parautochthonous, and limestones have moved westward above thin shale horizons, resulting in intense shearing at the soles of the thrusts. The imbricated succession was then deformed by northeast-trending, open and tight, westward-verging, overturned folds. Cleavage is locally developed and limestones are highly sheared in zones of high strain.

The third structural terrane is mostly in fault contact with the second terrane. It consists of tightly folded Goose Tickle flysch, northwest-directed thrust slices of Ordovician limestone, and Northwest Arm Formation mélange. Folds are overturned and westward facing. They trend northeast to north, have variable plunges of 5 to 25° southwest and northeast, and have a well developed, axial planar to fan cleavage. Thrusts have developed at the crests of pinched, west-verging anticlines that are cored by Table Point limestone.

Tuke (1968) showed the Northwest Arm mélange as imbricated with the Goose Tickle flysch. Williams and Smyth

(1983) concluded that the contact between the two rock units is a somewhat soft, irregular, tectonic contact. The contact in Pistolet Bay and Hare Bay is defined by a strongly flattened shale containing thin sandstone and intraclastic conglomerate beds.

The Northwest Arm Formation, itself, has been described as a mélange of sedimentary blocks in a chaotic green and black shale matrix (Williams and Smyth *in* Bostock *et al.*, 1983). However, green and black layering is clearly present in the shales. In addition, facing directions ascertained by grading, sole marks and cross-lamination in dismembered beds of the 'mélange' show that there is some continuity to the dismembered strata. These facing directions show that much of the succession was inverted and folded prior to deformation by the later, main phase of northeast-trending folds.

A mélange of similar character, but composed of Goose Tickle sediments in Wild Bight, Hare Bay, lends support to this idea. The Goose Tickle mélange is part of an inverted succession. Just west of Fournier Point, inverted Table Point limestone structurally overlies Black Cove shale and Goose Tickle flysch, which has disintegrated to mélange. Enclosed in the mélange are rafts of Cape Cormorant Formation and Table Point limestone breccia, as well as siliciclastic components. Facing directions in thick sandstone beds in the Goose Tickle indicate the presence of recumbent folds in the melange that are refolded by the later northeast folds. Type 1 and type 3 (Ramsay, 1967) interference patterns also occur, confirming the early recumbent structure.

Long, sinuous, northeast-trending faults with normal and reverse throws extend along the length of the carbonate belt. The main fault system is the Ten Mile Lake Fault zone which is a braided system of northeast- and north-trending splay faults. Narrow wedges of upthrown and downthrown strata occur within the zone. West-, northwest-, and southwest-trending faults also occur, in many instances these offset the northeast-trending faults. Downthrow on many of these faults is to the north.

These basic structural elements provide the framework for a tectonic history of the area. Infill of the Middle Ordovician flysch basin was terminated by emplacement of recumbently folded and dismembered sediments of the Northwest Arm Formation. During this early phase of Taconic deformation, thin skins of carbonate rock were imbricated with the Goose Tickle shales. These early structures were subsequently deformed by a later phase of northeast-trending, west-verging folds and westward overthrusting. The flysch and carbonate terranes were decoupled and a regional penetrative cleavage was developed in the more easterly terrane. Vertical displacement along high angle faults determined present outcrop patterns.

MINERALIZATION

Pyrite and sphalerite mineralization including some galena is widespread in the map area. The numerous showings can be essentially subdivided into two strata-bound zones. The first zone occurs in epigenetic dolostones and spar and matrix breccias that occur in the lower half and along the base of the Boat Harbour Formation. In some instances, the breccias step down into the Watts Bight Formation. Included in this zone is the Round Pond Prospect, reported to contain 152,000 tonnes of 2.5 percent Zn, Rhodes (1970, 1971). Sphalerite showings at Hidden Pond and Twin Ponds lie within the matrix and spar breccia bodies of this same interval. Pyrite is generally the most common mineral but sphalerite and galena are disseminated in some bodies. Showings near Watsons Brook and at Twin Ponds occur in higher intervals of the Boat Harbour Formation where dark-gray dolomites and pseudobreccia replace limestone beds. Small pods of matrix breccia are also present.

The second group of showings is in dolomites that have replaced limestones of the second and third members of the Catoche Formation. North Boat Harbour showings 1 to 5 (Hibbard, 1984a) and those at North Sawmill Pond (Hibbard, 1984b) and at Whale Pond occur in these epigenetic dolostones. The red-brown to green-yellow, fine to coarsely crystalline sphalerite is generally disseminated in pseudobreccia or more massive dolostones close to limestone-dolostone contacts.

Epigenetic dolostones that replace limestones at the base of the Table Point Formation (locality 4, Figure 1) and at the new St. Anthony airport contain sphalerite mineralization. Coarse brown-red crystals of sphalerite occur in dark gray to gray, dolospar-veined, fine to medium grained, crystalline dolostone at the lineament at locality 4. At St. Anthony airport, green sphalerite occurs in a pod of white crystalline dolomite that is intensely veined.

Sphalerite mineralization in the map area has been assumed to compare in genesis and timing to that at Daniel's Harbour (summarized by Cumming *in* Bostock *et al.*, 1983). When stratigraphic mapping began in the map area in 1977 and 1979 it became clear that many of the numerous showings, including the Round Pond Prospect, occurred in the Boat Harbour Formation. This stratigraphic interval, 250 m below the host horizon of the Daniel's Harbour Mine, lead Knight (1980, 1984) to suggest a second strata-bound target besides the secondary dolostones of the Catoche Formation. Dolomitization and creation of spaces in the Boat Harbour Formation was linked tentatively to the Boat Harbour 'disconformity'.

There is now sufficient evidence in the area and elsewhere on the Northern Peninsula to confirm late Arenig faulting of the platform and the presence of a late Arenig hiatus that essentially coincides with the contact between the St. George and Table Head groups. Matrix breccias, which formed in rocks of the Boat Harbour Formation, may have been controlled in part by the faulting. The faults, in particular the precursor to the Ten Mile Lake Fault system fractured the carbonates, creating fracture permeability. This provided subterranean channelways for solutions that not only caused dissolution but also extensive dolomitization. Later, when metal-bearing brines entered the system, they formed sites of low-grade mineralization. Clearly, during late Arenig karstification, the Boat Harbour strata could have been readily affected as suggested in Figure 4. The presence of sphalerite mineralization in dolomitized strata of the Table Head Group suggests metals were precipitated following the deposition of the Table Head Group.

ACKNOWLEDGEMENTS

The author is grateful for the assistance of Lawrence Patey and his family of Hawkes Bay during the field season. Doug Boyce, Sheila Stenzel, Noel James and a few others who strayed off Route 1 (TCH) shared the excitement of life on a deformed carbonate platform. S.P. Colman-Sadd and W.D. Boyce are thanked for critically reviewing this paper.

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