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GAC (NFLD) FALL FIELD TRIP

GEOLOGY OF THE SOUTHWEST COAST OF NEWFOUNDLAND

LEADERS

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The Anatomy of a Lower Paleozoic Petroleum System, Port au Port Peninsula

and

A transect of part of the Western Newfoundland lower Paleozoic Foreland Fold and Thrust Belt near Corner Brook

INTRODUCTION

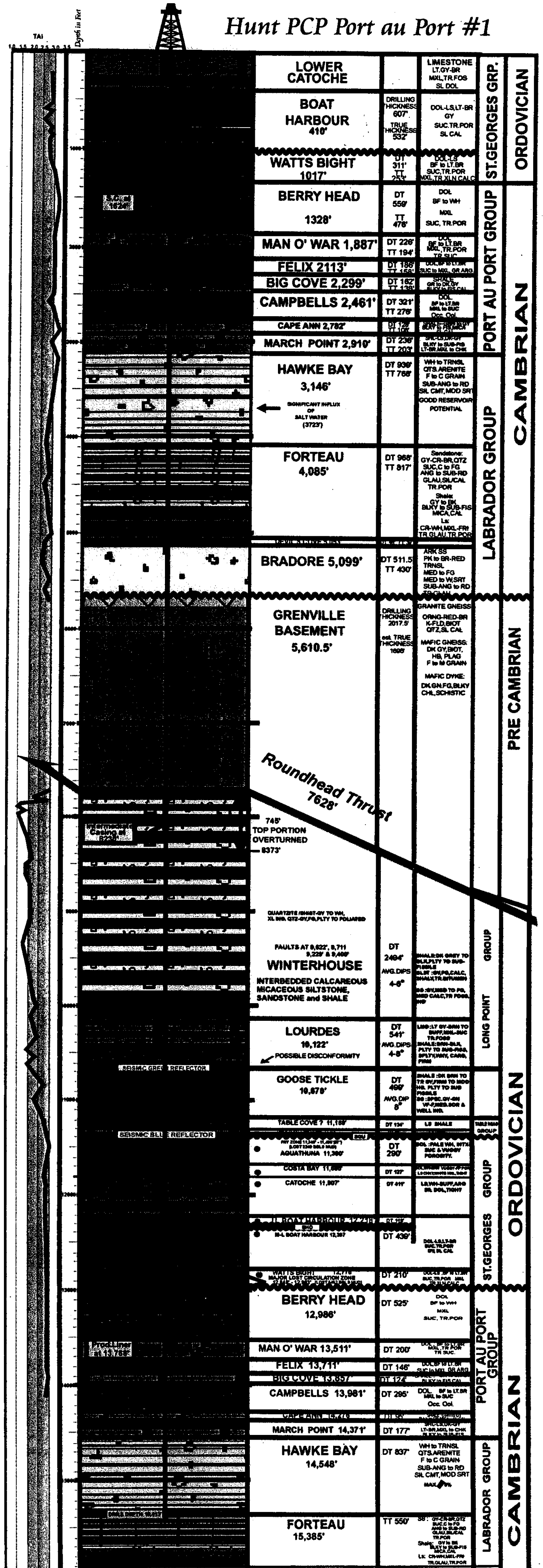
OBJECTIVES

This year's field trip provides an opportunity to review some parts of the shelf and foreland basin terranes of the *Western Newfoundland Foreland Fold and Thrust Belt* (WNFFTB) of the outer domain of the Humber Tectonostratigraphic Zone of Williams (1978). The WNFFTB deforms rocks of Precambrian to Devonian age and comprises western and eastern zones. The western zone, which will be visited on day 1 comprises thick skinned thrusts that are cored by Precambrian basement, are limited in their displacement, and involve the complete stratigraphic package of unmetamorphosed Cambro-Ordovician shelf and flyschoid sedimentary rocks. The eastern zone, the focus of day 2, consists of thin skinned structures that include a number of thrust stacks. The stacks comprise increasingly more distal packages of the Middle Cambrian to Middle Ordovician carbonate sequence and overlying Middle Ordovician foreland basin siliciclastic flysch sequence. The sequences in the eastern zone are metamorphosed from slate to low-greenschist grade. Both parts of WNFFTB predate late Mississippian (middle Visean) to Pennsylvanian (Stephanian) wrench controlled basins those sediments unconformable onlap the WNFFTB.

The western zone is host to numerous oil shows and several deep exploration wells, one of which discovered oil and gas at the western end of Port au Port Peninsula. The 1995 Garden Hill discovery well, drilled jointly by a partnership of Hunt Oil Ltd and Pan Canadian Petroleum Ltd of Calgary, followed an onshore and offshore seismic program that identified several target structures. The well (Port-au-Port No 1) flowed gas-rich high-quality oil up to 5000 barrels a day. The well is now licenced to Canadian Imperial Venture Ltd who are presently entering the delineation and development phase of the potential field. The size of the discovery has been re-evaluated following a recent fill-in seismic program by Canadian Imperial Venture Ltd that indicates a much larger potential field. During Day 1, we will stop at the various sections on the peninsula which will provide the architecture of the petroleum system. This includes parts of the C–O shelf sequences, that are host to dolostones and paleo-cave systems linked to regional disconformities in the sequence and provide the reservoir. Also we will view the source rocks that provided the hydrocarbons to the system and visit localities that illustrate the early synsedimentary structural history of the shelf, and how such early structures relate to reservoirs and to later deformation. Finally, we will view stratigraphic and structural relationships of autochthonous, allochthonous and neoautochthonous sequences that help define the timing of the structural events that shape the peninsula.

The eastern zone, near Corner Brook, hosts low-grade metamorphic equivalents of the C–O shelf and flysch sequence. These rocks are preserved in the Goose Arm thrust stack to the north of Corner Brook and the Blue Pond thrust stack to the southwest. Both stacks formed in the footwall to the Humber Arm Allochthon and are polydeformed. Stratigraphy and sedimentary facies of the Middle to Upper Cambrian carbonate shelf change eastwards from thrust to thrust. Metamorphic grade intensifies as the stack is followed from west to east. Both imbricate stacks include a

Hunt PCP Port au Port #1



CORELDRAW / PRT#1 96.CDR DRAWN BY T.Kaczmarski PRINT DATE : Sept18 / 97 distinctive sequence of off-shelf carbonates and shales defined as the Weasel Group. This group is time equivalent of part or all of the C–O shelf carbonates. As such it locally underlies the Cambrian shelf carbonates in more easterly thrusts. Two structurally high thrust slices that immediately underlie the Humber Arm Allochthon however carry the full stratigraphic expression of the group. Lastly, metamorphism transforms the carbonates into marbles, some of which are potential dimension stone prospects and have been quarried. MVT mineralization is also locally hosted by the carbonates of the thrust stacks.

Stratigraphic Framework

The stratigraphy of the Cambro-Ordovician shelf sequence is outlined in Figure 1 and chronostratigraphic relationships of coeval shelf and offshelf sequences and foreland basin sequences in western Newfoundland are illustrated in Figure 2 (from Cooper *et al.*, 2001). The succession preserved in autochthonous rocks of western Newfoundland consists of a number of sedimentary packages that have been defined as phases and megasequences by different studies (James *et al.*, 1988; Cooper *et al.*, 2001). Essentially, it consists of 3 tectono-stratigraphic packages.

The first package consists of late Proterozoic rift sediments and volcanics that are preserved in rocks of the lower Labrador Group but also widespread in the Taconian allochthons that form a dominant place in the Humber Zone. Conglomeratic sandstones and basic volcanics fill the narrow rift basins bounded by active faults. Radioisotope dates on volcanic feeder dykes and other associated rocks suggest rifting at about 605 to 615 Ma. These rocks are not present in the area of the field trip.

The second package comprises a relatively long-lived succession of siliciclastic and carbonate sediments deposited along a long passive margin from late Early Cambrian essentially until the end of the Early Ordovician (Arenig). The margin lay south of the paleo-equator where it was bathed by the clear shallow tropical waters of Iapetus Ocean. The sedimentary record of the passive shelf begins with the late Early Cambrian to Middle Cambrian upper Labrador Group. This is a mixed sequence of siliciclastics and carbonates deposited in fluvial coastal plain and open marine shelf settings during a megacycle of flooding and offlap. It includes some of the earth's oldest skeletal reefs.

The passive margin sequence is dominated, however, by carbonate shelf rocks of the late Middle Cambrian to Late Cambrian Port au Port Group and the Early Ordovician St. George Group. The carbonates consists of megasequences composed of subtidal and peritidal carbonates arranged in meter-scale parasequences. Three Grand Cycles are recognized in the Port au Port Group (Chow and James, 1985; Cowan and James, 1993) and two megacycles in the St. George Group (Knight and James, 1987). The Cambrian Grand Cycles are essentially megasequences of subtidal shaly nodular limestone that shallow upwards into thick oolitic carbonate grainstone shoal complexes, and/or peritidal cyclical carbonates, including stromatolitic and oolitic limestones and mudcracked dolostones deposited in tidal lagoon and flat settings.

The St. George Group megacycles consist of a disconformity-bound sequences of formations of Tremadocian and Arenig age (Knight and James, 1987). The sequences consist of a basal sequence of peritidal carbonates that give way upwards to subtidal, open shelf, burrowed, fossiliferous and thrombolitic limestone, the product of eustatic flooding of the shelf. The high stand flooding strata are overlain by formations of peritidal dolostones and limestones as the shelf shallowed later into the intertidal zone. Exposure produced regional disconformities which are locally cryptic and local karst surfaces. The St. George Group is capped by the regional St. George Unconformity, which formed in response to fall of sea level below the shelf edge accompanying passage of a migrating Taconian peripheral bulge across the margin (Knight *et al.*, 1991). Karstification and erosion produced significant relief on the unconformity in response to active block faulting.

The third package consists of strata laid down in a Taconian to Acadian foreland basin (Middle Ordovician to Middle Devonian) (Figure 2, from Cooper *et al.*, 2001). Its basinfill is the response to at least three tectonic episodes along the margin. Two of these basinfills reflect Taconian events related to, a) the passage of a flexural bulge across the foundering margin in the Llanvirn, and b) development of a late Ordovician Taconian basin after the emplacement of the Cow Head Group rocks into the basin in the Llandeilo. The later basinfill consists of the Caradocian Long Point Group The last basinfill comprises predominantly non-marine redbeds of the Clam Bank and Red Island Road formations, reflecting Salinian and possibly Acadian deformation along the margin (Cooper *et al.*, 2001).

The earliest of the foreland basin fill is an early Taconian mega sequence of Middle Ordovician carbonate shelf and overlying sandy and shaly flysch of the Table Head and Goose Tickle groups. The groups preserve the record of Llanvirnian deepening as the ancient continental margin foundered with Taconian accretion. The lower carbonate shelf package of the Table Point Formation preserves a peritidal to subtidal shelf sequence that was deposited on a narrow deepening ramp shelf. The basin not only inherited the uneven topography of the St. George Unconformity but was effected by active faulting. This lead to locally restricted to discontinuous stratigraphy during the transition from carbonate shelf to flysch. Continued block faulting segmented the Taconian basin into a series of fault-controlled arches and subbasins (Figure 3). Carbonates were eroded from the highs and carbonate conglomerates deposited into adjacent lows (Daniel's Harbour Member and Cape Cormorant Formation). An anoxic basinal shale (Black Cove Formation) widely blankets much of the basin below thick sandy and shaly flysch of the Goose Tickle Group. The flysch basin was a dominantly southwest-trending trough in which most currents flowed from the northeast along the basin axis. Pebbly sand-dominated sections mark submarine fans that accreted from the orogen to the southeast.

The emplacement of the Taconian klippe of deep-water Cow Head Group and overlying Lower Head Formation flysch into the foreland basin at least as far west as the western tip of Port au Port Peninsula brought this phase of the foreland basin to an end. Associated with the emplacement are both conglomerates and broken formation. Shale pebble conglomerates derived from erosion of the Cow Head rocks occur locally in the top of the Goose Tickle flysch (Knight, 1986, I. Knight and D. Boyce, unpublished data 2000). Broken formation assigned to the Goose Tickle Group overlies Goose Tickle flysch extensively throughout the foreland basin (Knight, 1986, 1997; Knight and Boyce, 2000) and is mixed with allochthonous rubble in the southern part of the basin to form breccias (Waldron *et al.*, 1993, Cooper *et al.*, 2001) as the leading edge of the allochthon moved into the basin.

The allochthon was later onlapped, unconformably, by the Caradocian Long Point Group that forms the upper Taconian basinfill. Like its Llanvirnian counterpart, the Long Point Group consists of a basal shelf limestone associated with some shoreline sandstones (Lourdes Formation) overlain by deeper water flyschoid sandstone and shale, the Winterhouse Formation. The latter shallows into rocks of the Misty Point Formation.

The Salinic to Acadian basinfill is marked by a basal unconformity. The Clam Bank Formation is dated by marine fossils as Pridolian (i.e., latest Silurian) suggesting a long-lived hiatus of about 50 M years separated the Taconian basinfills from the later Salino-Acadian sequence. This hiatus probably marks the Salinic deformation in central Newfoundland (Cawood *et al.*, 1994; Dunning *et al.*, 1990; Cooper *et al.*, 2001). The Clam Bank Formation consists of mixed marine and non-marine siliciclastic and carbonates at the base coarsening upwards into red fluvial sandstones and conglomerates. Non-marine fluvial sedimentation possibly continued uninterrupted into the Emsian (Middle Devonian). The Red Island Road Formation is a red, coarse pebbly sandstone, deposited by braided streams. Sedimentation was terminated with the propagation of Acadian deformation across the basin.

Structural Framework

The outer domain in the Humber Zone of western Newfoundland comprises Precambrian basement overlain by an autochthonous to parautochthonous lower Paleozoic cover sequence, Taconian allochthons that rests structurally above the autochthon, and neoautochthonous foreland basin sequences. The zone is divided structurally into 3 zones: 1) an essentially undeformed zone that occurs only in the northwestern most part of the Great Northern Peninsula and in southern Labrador; 2) a western zone of thick skinned deformation that involves essentially the cover sequence and crystalline basement; and 3) an eastern zone of thin skinned deformation that includes several imbricate thrust stacks (Figure 4 and 5, from Cooper *et al.*, 2001). Deformation is divided between 3 orogens, Late Ordovician Taconian orogen, Silurian Salinian orogen and Devonian Acadian orogen. Deformation has been traditional linked to the Taconian and later Acadian deformation. The Taconian event, however, was probably principally significant for the emplacement of the allochthon onto the margin and the foreland basin. Much of the structure in the domain is assigned to Silurian deformation associated with Salinian Orogenesis and later Acadian deformation (Knight and Cawood, 1991; Cawood *et al.*, 1994; and Cooper *et al.*, 2001). Generally, the Taconian allochthons are considered to be the roof to the eastern, thin-skinnned zone of imbricate thrust stacks. Nonetheless, in the western thick skinned zone, the Taconian allochthons rocks, i.e., rocks of the Cow Head Group, are clearly deformed much later in the Acadian, only to be inturn deformed by some of the thick-skinned structures.

In the eastern thin-skinned zone, the stacks of west-verging thrusts appear to override rocks of the foreland basin of largely intact and broken formation of the Goose Tickle Group (Knight, 1994, 1997). The stacks elevated the roof rocks of the Taconian allochthons in an anticlinal culmination, so that later erosion breaks the allochthon into two, the Humber Arm Allochthon and its smaller outlier, the Old Man Pond Allochthon. Mylonites of foliated carbonates that form the sole of many thrusts carrying strong lineations, C-S fabrics, augen and recumbent folds, all of which give a northwest sense of vergence. The early structures are deformed by penetrative southeast-verging folds and cleavage that fashion much of the northeast-trending fold pattern of the domain. The timing of the thrust stack is not definitely established and may span both Salinic and Acadian phases. However, the 2-phase deformation may be solely Salinic in origin. A comparable thin- skinned thrust stack in the Canada Bay area i.e., phase-1 thrusts deformed by phase-2 penetrative structures is intruded by a suite of basic dykes dated by Ar/Ar methods that suggest the deformation may be entirely Salinic (I. Knight, unpublished data). Metamorphic grade increases as the thrust stacks are traced eastward ranging from slate grade in the west to low greenschist in the east.

Much of the western thick-skinned terrane is dominated by a series of large, northeast-trending fold structures that include from east to west the North Brook anticline, the Phillips Brook anticline and the Table Mountain anticline (Figure 6). The structures are largely east-verging in the hangingwall of high-angle faults along the eastern side of the structures. The Phillips Brook structure, however, is bounded by faults on both east and west sides supporting a popup structure. Major linear faults dissect some of these structures suggesting late wrench faulting. Autochthonous and basement rocks of the Port au Port Peninsula are part of a largely east-trending, north-dipping ridge. However, the peninsula is host to both northwest- and northeast-trending folds (like in the Table Mountain structure) which deform the hangingwall to major faults such as the Round Head Thrust, Red Brook detachment and Piccadilly Bay Fault (Figure 7, from Stockmal and Waldron, 1993). As such its structure is genetically linked to the other structures in the western thick skinned terrane (Stockmal and Waldron, 1993; Cooper *et al.*, 2001).

A triangle zone is mapped at the western end of the peninsula (Stockmal and Waldron, 1993; Cooper *et al.*, 2001). It comprises a roof thrust, the Tea Cove thrust (TCT), that carries west-dipping neoautochthonous rocks of the Long Point Group and Clam Bank Formation. In the footwall to the

Tea Cove Thrust, and forming the indentor, is an west-verging, imbricated package of rocks assigned to the Cow Head Group (Cooper *et al.*, 2001, see Figure 8). A basal detachment occurs at the base of the Cow Head Group and/or within the flysch close to the top of the autochthonous sequence; the cover rocks are generally not metamorphosed. These structures are generally considered to be Acadian in origin based on, 1) deformation of the Late Silurian to Middle Devonian succession by the Tea Cove hangingwall (Figures 7 and 8); 2) deformation of both the TCT and Silurian to Devonian succession by the Round Head Thrust (Figures 7 and 8); and 3) the stratigraphic onlap of the deformed rocks of the Peninsula by undeformed late Mississippian rocks of the Codroy Group. The Codroy Group is part of the Bay St. George Subbasin, a wrench basin with a protracted extensional history from Late Devonian through to the Pennsylvanian (Knight, 1983).

FIELD TRIP GUIDE

DAY 1

The Anatomy of a Lower Paleozoic Petroleum System, Port au Port Peninsula

Drive from Corner Brook to Stephenville (about 1 hour) and then west to Port au Port Peninsula. After crossing the isthmus to Abbot and Haliburton general store, turn left onto route 460, the south shore highway of the peninsula and drive 1.1 km to Spruce Pine Acres. Park here and walk down to the coast through the grounds. Take care as you walk down the wooden stairs to the shore. Stops are shown in Figure 9.

Stop 1.1 - Green Point: Microbial mound and grainstone complex, Watts Bight Formation and Lower-Middle Boat Harbour Disconformity (Time allocation 1 hour).

The Watts Bight Formation on the Port au Port Peninsula is dominantly subtidal bioturbated limestone with storm layers of intraclastic conglomerate and high-energy thrombolitic mound complexs. The carbonates were deposited during the earliest Tremadocian/Canadian flooding and offlap of the western Newfoundland shelf. This locality is famous for its study of the spectacular thrombolitic mounds that are common in the formation throughout western Newfoundland and which were described by Pratt and James (1982). The mounds are subtidal cryptalgal microbialites having clotted and digitate structure, that also hosts sponges, primitive corals (*Lichenaria*) and stromatoloporoids (*Pulchrilamina*). They are associated with channel-fills and beds of grainstone as well as exhibit erosional surfaces that imply the shelf had shallowed into the surf zone. Both the mounds and the carbonate sand are partially dolomitized. The finely sucrosic dolostones have pin-point porosity.

Traced northward the Watts Bight Formation is overlain by the lowest beds of the Boat Harbour Formation. The unit consists of several meter-scale peritidal limestone-dolostone sequences capped by a thick interval of dolostone. Bioturbated limestone overlain by dololaminite reflect the gradual shallowing of the shelf into the intertidal zone. Small pockets of breccia, long fissure cracks and sheet cracks and the widespread presence of chert all point to a disconformity at the top of the thick dolostone, just beside the ladder to the inn. This is supported by marked change in micro and macrofaunas at this point in the stratigraphy. Elsewhere in western Newfoundland, this interval is a characterized by massive development of collapse breccias, an ideal reservoir.

Above the dolostone unit, the middle Boat Harbour Formation is characterized by more peritidal limestones and dolostones that were deposited throughout the Demingian. Note the superb stromatolite mounds just north of the ladder.

Return to vehicles and drive back toward Abbot and Haliburton, about 0.7 km, park at crest of hill and walk down to shore through field, turn south along shore to next stop (Time allocation 1 hour).

Stop 1.2 - Isthmus Bay, Boat Harbour Disconformity

This shoreline section preserves a classic exposure of a disconformity between Tremadocian and Arenigian carbonates of the middle unnamed member and the upper Barbace Cove Member of the Boat Harbour Formation (Knight and James, 1987). The surface is somewhat cryptic because metre-scale peritidal carbonates occur above and below the break. The surface is marked by erosion, underlying karst features such as paleocaves, fissures, breccias and again fairly extensive dolomitization and silicification in sub-disconformity carbonates. Karst surfaces also mark the tops of at least two parasequences below the disconformity suggesting that offlap was gradual. The disconfomity is overlain by a basal conglomerate. Micro and macrofaunas change across this boundary, in particular trilobites of subzone G_1 are missing suggesting prolonged exposure of the shelf at this time (see Doug Boyce for details). The surface marks a major sequence boundary at the base of an Arenig flooding event that is known to control carbonate sedimentation around continental margins throughout the Ordovician globe.

Walking upsection back to the truck, note the metre-scale subtidal to supratidal cycles, the impressive mudcracked laminated limestones and dolostones that mark the top of the Boat Harbour Formation. Also note the fossiliferous and burrowed dolomitic limestones with intraclastic conglomerates that characterize the overlying Catoche Formation, a widespread subtidal shelf carbonate found throughout western Newfoundland.

Drive back to the Abbot and Haliburton junction, turn left and proceed to Aguathuna quarry, 3.4 km to the west.

Stop1.3 - Aguathuna quarry, St. George Unconformity, associated paleo-karst features and bounding stratigraphy (Time allocation 1 hour).

The St. George Unconformity is a regional unconformity correlated with the Knox Unconformity in the southern Appalachians. It forms a major sequence boundary in the Appalachians, marking the Arenig-Llanvirn boundary and separating the Sauk and Tippecanoe sequences of Sloss (1963). It also marks the contact of underlying carbonates of the St. George Group deposited along the Laurentian passive margin of Iapetus Ocean and those above of the Table Head Group that were deposited in a Taconian foreland basin. The boundary is believed to be largely the product of passage of a peripheral forebulge across the margin coincident perhaps with an eustatic sea level fall (Knight *et al.*, 1991).

The unconformity is brilliantly exposed in the face of the outer quarry where it shows erosional relief of several metres cut down into the predominantly burrowed and laminated dolostones of the Aguathuna Formation, St. George Group. The surface hosts local karren draped by pockets of rubbly protosoil and a basal conglomeratic lag and subsurface cave deposits. Bedding plane caves marked by protruding floor pillars and ceiling teeth also occur in the subsurface. The caves formed where limestones were dissolved from between dolostone beds. Such caves are important reservoirs in the Garden Hill well.

The Table Point Formation consisting of dark grey bioturbated limestones overlies the unconformity. A thin member of fenestral limestones occur immediately above the unconformity, known as the Spring Inlet Member. These were deposited as the Middle Ordovician sea drowned the unconformity.

Drive into the inner quarry where the top of the Catoche Formation and the base of the Aguathuna Formation are exposed. The Catoche Formation consists of two units, a lower tan grey sucrosic dolostone overlain by a white clean limestone, the Costa Bay Member. Paleocaves and collapse breccias occur throughout this quarry. The reservoir potential of cave system in this area is however reduced by clogging with green shale that was probably derived from the unconformity and by subsurface washout of interbedded shale beds in the base of the Aguathuna Formation. Note the massive bedded nature of the Costa Bay Member here where it is composed mostly of peloidal grainstones. Elsewhere in western Newfoundland it is the host to extensive dolomitization and impressive porosity as at Port au Choix. By the time we get to the west ern part of the Port au Port Peninsula the member will have changed its character and will again host some porous dolostones (Stop 1).

Return to route 460 via Father Joys road and drive west to Piccadilly Head where we will continue to the entrance of Piccadilly Park, a distance of 24 km. Note as we drive through Piccadilly, the long limestone scarp that marks the trace of several faults including the Carboniferous dextral Piccadilly Bay Fault and the east-verging Red Brook detachment of Stockmal and Waldron (1993) which converge toward the headland. Critical to the petroleum system are the presence of synsedimentary faults that control diagenesis, block faulting, erosional highs on the St. George Unconformity, sedimentary facies and later fault inversion during orogenesis. The early history of the Middle Ordovician foreland basin was probably a complex of fault-bounded subbasins with facies variable both lithologically and in thickness (see Figure 3). The next two stops illustrate some of the features of one such subbasin.

Stop 1.4 - Piccadilly Park, Daniel's Harbour Member, American Tickle Formation, Goose Tickle Group (half hour duration).

The Daniel's Harbour Member is a limestone conglomerate derived from erosion principally of the Middle Ordovician Table Point Formation and bounded by basinal and flyschoid siliciclastics of the formations of the Goose Tickle Group. In the park, the member is of significant thickness suggesting that it was laid down proximal to a fault-bound high. Such thick conglomerates were deposited in hangingwall basins of extensional faults, to be later inverted during compression. The conglomerates rapidly thin and wedge out into the basins as can be demonstrated by our next stop at Piccadilly quarry just 0.5 km to the west.

Stop1.5 - Piccadilly Quarry, Top of Table Point Formation, overlying Table Cove Formation, Black Cove formations and a thin Daniel's Harbour Member (half hour duration).

The quarry is well known for its common fossils in the Table Cove Formation. The latter is a succession of interbedded fine grained ribbon limestones and shales that were deposited locally in slope settings adjacent to the carbonate shelf or platforms in some but not all subbasins. The fossils include several graptolites, the trilobite *Cybelurus mirus* and inarticulate brachiopods. The fauna is middle Llanvirn in age. An oil seep is present in the southeast corner of the quarry. The Black Cove Formation that overlies the ribbon limestones is a dark grey, organic rich shale that is a potential source rock with TOC of up to 2 percent. The thin Daniel's Harbour Member occurs in the upper terrace of the west face of the quarry.

Crossing the highway and walking down to the shore, the base of the allochthon consisting of shaly rocks of the Cow Head Group overlies broken Table Cove Formation and deformed Goose Tickle Formation turbidites and shales. The deposits of the Cow Head Group throughout the Port au Port Bay area are probably equivalent of the Green Point Formation, a succession of shales, ribbon limestones and minor resedimented limestone conglomerate.

Return to vehicles and drive along route 463 about 4 km to small family farm. Park on the gravel shoulder and walk north through the farm along a track to coast.

Stop 1.6 - Black shale of Green Point Formation (half hour duration).

Black shales at this stop are well known as potential petroleum source rocks. The shales host beautiful pyrite nodules and have TOC values of up to 10 percent. The organic component is the microbe *Gloeocapsomorpha* sp. (Fowler *et al.*, 1995).

Drive west again along rte 463 for 3 km to Tea Cove road. Drive down to the shore.

Stop 1.7 - Overview of Tea Cove to describe the Tea Cove Thrust and other elements of the Tea Cove triangle zone (half hour duration).

The Tea Cove Thrust is a west-dipping structure that was proposed by Stockmal and Waldron (1993) to form the roof thrust of the triangle zone. West-dipping sandstones and limestones of the Lourdes Formation of the Long Point Group are carried in the hangingwall of the thrust and form the scarp along the east shore of Long Point. The footwall to the Tea Cove Thrust is the indentor of the triangle zone. It consists of the Cow Head Group overlain by coarse pebbly flysch of the Lower Head Formation. Mapping of the shoreline of the bay and well logs of the Long Point M-16 well at the tip of Long Point (see Figure 8, from Cooper *et al.*, 2001) indicate that the allochthonous rocks are thickened by a imbricate thrust stack that includes both west and east-verging structures as well as east-trending structures. The base of the allochthon was likely the basal detachment upon which the shortening occurred.

Drive about 1 km west of the Tea Cove Road junction with route 463. An outcrop of sandstone occurs on the south side of the road. Care is needed to observe oncoming traffic with the bend in the road.

Stop 1.8 (optional) - Lower Head Formation, pebbly flysch.

Thick beds of pebbly coarse grained sandstone are characteristic of the more proximal foreland basin flysch that was deposited above the deepwater shale sequences of the Cow Head Group. Note that there are numerous pebbles of green and black shale derived from cannabilization of the Green Point Formation.

Continue to drive west through and south towards Round Head and Three Mile Rock a distance of about 8 km. Note the overturned Lourdes limestone at the school as we pass through Lourdes. Enter the aggregate quarry to the left of the highway and drive to the foot of Round Head.

Stop 1.9 - Aggregate quarry foot of Round Head, Cape Cormorant Formation.

The scarp above our heads is a very thick succession of amalgamated limestone conglomerates of the Cape Cormorant Formation that ride upon the Round Head Thrust (RHT), which probably underlies the gravel pit. The formation was carried in the hangingwall to the RHT during the inversion of the adjacent foreland basin and underlying shelf succession along the fault during Acadian deformation. The formation has been placed in the Table Head Group (Klappa *et al.*, 1980; Stenzel *et al.*, 1990) but is probably better as part of the Goose Tickle Group. For instance, the formation either sits with the erosional base upon the Table Point Formation as near Big Cove or rests above shales of the Black Cove Formation which is assigned to the Goose Tickle Group east of Round Head. The massive conglomerates formed like their counterpart, the Daniel's Harbour Member, in hangingwall subbasins at the foot of active fault scarps as the foreland basin shelf foundered. The formation however taped source rocks deep within the Cambro-Ordovician passive margin shelf suggesting that the Round Head Fault, a major long-lived fault, uplifted and exposed shelf carbonates to the west which were extensively mined by erosion of the arch (Figure 10, from Cooper *et al.*, 2001). Conglomerates in the type section near Mainland have boulders and house-sized blocks of carbonates as old as the early Late Cambrian Petit Jardin Formation, Port au Port Group. In addition, stratigraphically younger conglomerates host gradually older carbonate clasts (Stenzel, 1992) At Round Head, the conglomerates are believed to have taped the C–O carbonate shelf as deep as the Berry head Formation, top of the Port au Port Group. Detritus in the conglomerates seen here in large fallen blocks include Cambrian dolostones, many of which are rich in chert. As with the Daniel's Harbour Member, the conglomerates of the formation form very thick amalgamated deposits adjacent to the their source but rapidly thin and wedge out over no more than 1 or 2 km to the east into the flysch basin (Airphoto interpretation and mapping); two or three resistant wedge-shaped ridges of conglomerate separated by valleys of recessive shales and sandstones occur just east of the Head. Away from Round Head only thin conglomerates of Daniel's Harbour type can be found.

Return to route 463 and drive 2.7 km to the turnoff to Three Mile Rock fishing station, drive down to the station.

Stop 1.10 - Three Mile Rock, Overturned Lourdes Limestone, overview of the stratigraphic and structural relationships of the Triangle Zone and the Round Head Thrust; stratigraphic overview of Long Point Group and Clam Bank Formation by Helen Gillespie.

Stockmal and Waldron (1993) indicate that the overturned Lourdes Limestone lies in the footwall of the Round Head Thrust (RHT) and in the hangingwall of the Tea Cove Thrust (TCT) at this locality. If this is the case, the Lourdes Formation possibly originally rested disconformably upon the Mainland Formation flysch of the Goose Tickle Group which can be seen in the cliffs to the south of the point. The Goose Tickle Group is Llanvirnian and the Lourdes Limestone Caradocian.

The Lourdes limestone forms the base of a Caradocian foreland basin sequence that includes grey shaly siliciclastic flyschoid rocks of the Winterhouse and Misty Point formations. Looking north, overturned red beds of the Pridolian Clam Bank Formation include fluvial and shoreline sandstones and marine shelf carbonates that are part of a Silurian to Middle Devonian foreland basin sequence. Faunal evidence suggests that a significant hiatus of 20 million years separates the Caradocian basin fill from the Siluro-Devonian basin fill.

The youngest rocks of this Siluro-Devonian sequence are exposed as gently dipping upright red fluvial conglomerates and pebbly sandstones of the Red Island Road Formation on Red Island seen offshore to the south. These red sediments have yielded Emsian spores and are part of the hangingwall sequence to the TCT hence dating the timing of formation of the triangle zone as late Emsian or younger. The overturning of the Long Point Group and Clam Bank Formation in the footwall to the RHT suggests the latter cuts and deforms the TCT. Since flat-lying, middle Visean sediments onlap the hangingwall structure of the RHT and associated structures throughout Port au

Port Peninsula, the window of opportunity to deform the foreland basin ranges from Post Emsian to early Mississippian, a window of about 50 million years. This suggest that the deformation is either exclusively Acadian or could be both Acadian (TCT) and perhaps earliest Mississippian. Very coarse resedimented conglomerates rich having pebbles and boulders of unmetamorphosed E–O carbonate and Proterozoic crystalline basement occur mid way through the thick wrench basin fill of the Anguille Group in the Bay St. George Basin, south of the Peninsula. Since no evidence of E–O shelf detritus occurs in sandstones below the conglomerates it implies that the carbonates of the Peninsula were uplifted in the early Mississippian (Knight, 1983).

At the shore, the Lourdes limestone displays its characteristic fossiliferous, fine grained, nodular nature but is locally interbedded with crossbedded grainstones and intraformational conglomerates. Trace fossils are common and isolated stromatoporoids that indicate that the unit is inverted occur locally.

Return to route 463 and drive south for 21 km through Mainland, climbing the hill onto the limestone barren of the backbone of the peninsula. Outcrops of Mainland Formation flysch consisting of interbedded grey sandstones and grey shale occur in outcrops along the shore close to the road at Crow Head and in roadcuts near Mainland. Once on the limestone plateau, note several vertically walled, fault-controlled paleo-karst valleys that are filled by undeformed grey and red coarse conglomerate of probable Visean age.

Stop 1.11 - Transition of the Catoche Formation to the Aguathuna Formation, fossiliferous shaly limestones of the Costa Bay Formation, dolomitized grainstones with porosity, and peritidal carbonaes of the Aguathuna Formation (Figure 11).

This transition from Catoche to Aguathuna formations is unique in western Newfoundland and contrasts markedly with Stop 1.3 at Aguathuna quarry. The Costa Bay limestones are markedly cyclically of shaly nodular, fossiliferous and burrowed limestone capped by oncolitic and fossiliferous peloidal packstones and grainstones. The diverse fauna plus the presence of graptolites and pliomerid trilobites supports an open oceanic shelf setting (Boyce *et al.*, 2000). The transition into the peritidal Aguathuna Formation is marked by deca-thick unit of finely crystalline sucrosic dolostones that locally show crossbedding and were deposited in a high-energy carbonate sand shoal complex that lay seaward (south of) of a broad sheltered tidal flat (Aguathuna Formation). This unit that can be mapped over a significant area in the west of the Peninsula is host to pinpoint and intercrystalline porosity and may be typical of one of the reservoir in the Garden Hill discovery well. The Aguathuna Formation comprises meter-scale cycles of bioturbated and stromatolitic and less commonly intraclastic, oncolitic and peloidal grainy limestones capped by laminated limestones and dolostones. Silicified gastropod opercula are the most common fossil. At least one paleo-cave occurs in the section where dissolution of a limestone bed is replaced by a collapse breccia.

Continue south 7 km along route 463 to make a brief stop to admire the Canadian Imperial Venture Ltd's rig at Garden Hill and discuss the well stratigraphy and structural setting.

Stop 1.12 - Garden Hill Well (P-au-P No 1).

The well was drilled to approximately 4.7 km, penetrating over 1 km of crystalline basement in the hangingwall before passing through the RHT to penetrate an anticline between the RHT and a footwall shortcut fault (see Figure 8). Several reservoir zones were penetrated in the footwall sequence in the Aguathuna Formation and lower in the Watts Bight Formation of the St. George Group. Hydrocarbons were encountered in 3 zones in the Aguathuna Formation, including at least some cavernous porosity (paleo-caves) associated with vuggy sucrosic dolostones (hydrothermal dolostones since they are associated with sparry dolomite and some MVT mineralization) in a zone 18.5 m thick. Water saturated zones occur in Catoche Formation dolostones and in cavernous zones in the Watts Bight Formation.

Figure 12 shows the reconstruction of the pre-inversion structure across the Round Head Fault as interpretated from the well logs. A model of the hydrocarbon for the well is illustrated in Figure 10 (from Cooper *et al.*, 2001).

Return to Stephenville and Corner Brook along the south shore of the Port au Port Peninsula (route 463).

DAY 2

A transect of part of the Western Newfoundland Lower Paleozoic Foreland Fold and Thrust Belt near Corner Brook

MOST OF THE STOPS ARE LOCATED ALONG THE TCH. CARE IS IMPORTANT WHEN ALIGHTING FROM AND RETURNING TO VEHICLES AND WHEN CROSSING THE HIGHWAY.

During the first part of the day, we will look at some parts of the Goose Arm thrust Stack north of Corner Brook (Figure 13). The stack consists of several thrust slices where the rocks are polydeformed but metamorphic grade is quite low so that fossils and petrographic character of limestones and dolostones are still recognizable. Later, we will travel southwest of Corner Brook to look at parts of the Blue Pond Thrust Stack where there are again several thrust slices and polydeformation (Figure 14). However, the metamorphic grade is higher with significant recrystallization of the limestones. We will also look at coeval off-shelf mixed carbonates and siliciclastic of the Pinchgut Lake Formation that are carried in the Pinchgut Lake Thrust. Both thrust stacks are characterized by northwest-verging thrusts and associated structures that are deformed by later southeast verging fold and thrusts associated with a penetrative northeast trending cleavage.

Leave Corner Brook and cross the Humber River enroute to Hughes Brook. Just east of Hughes Brook, turn north onto the Goose Arm gravel road and drive north to Old Man Pond.

Stop 2.1 - Goose Arm Road near the western end of Old Man Pond; overview of the area, and relationship of carbonate platform in footwall to Taconian allochthon. The Reluctant Head Thrust (Stop 2.2) occurs on the north shore of the lake.

Stop 2.2 - Major bend on the Goose Arm road above Old Man Pond at location of the Reluctant Head Thrust and exposure of the Reluctant Head Formation in hangingwall.

Interbedded ribbon limestones and phyllites associated with bedded limestones and limestone conglomerates of the Reluctant Head Formation. The Middle to Late Cambrian rocks are deformed by north-verging D1 structures including transposed bedding along the penetrative cleavage. The D1 structures are folded and crenulated by essentially south-verging D2 structures and cleavage. Footwall to the thrust are bedded limestones and dolostones of the Boat Harbour Formation, St. George Group that outcrop south of the road.

Return to Corner Brook and proceed west of the city to Georges Lake.

Stop 2.3 - Overview of the sole of the Blue Pond Stack Looking back eastward along the TCH and the trace of the hydro power line, outcrops of Cambrian carbonates of the Port au Port Group sit structurally above broken formation of Goose Tickle Group and Taconian allochthonous sediments that outcrop along the TCH. To the southwest, a circular window of the footwall slates surrounded by hills of thrust shelf carbonates are key to recognizing the structural relationships of the area.

Stop 2.4 - TCH about 0.7 km northeast of 2.3, broken formation of the Goose Tickle Group, Taconian allochthon. Sandstones and slates, typical of the footwall to the stack. The sandstones show faint lamination, slates host a penetrative cleavage which carries a crenulation lineation. Pyrite is common here. Fractures filled by crystalline bitumen occur at this locality.

Stop 2.5 - Drive 3.7 km to northeast on TCH to outcrops opposite Georges Lake. Vertically dipping to overturned folded rocks of the Middle Ordovician Table Point Formation in the footwall to the Blue Pond Stack. These rocks, which include nodular to lumpy dolomitic limestones and argillaceous and dolomitic ribbon limestones, resemble rocks of the Cambrian Reluctant Head Formation; however, gastropods support the younger formation. The strata is folded about a north-plunging folds with a steep east-dipping cleavage. Both bedding and cleavage are deformed by northeast-trending S2 northwest dipping crenulation cleavage.

Stop 2.6 - TCH about 7 km to the northeast of Stop 2.5 and stop at the crest of hill by Maggie's Seafood Gallery sign overlooking Pinchgut Lake. This is one of the outcrops critical to understanding the geology of this area. The high road cliff on the north side of the highway hosts folded and polydeformed limestones and dolostones of the Table Point Formation overlying dolostones of the Aguathuna Formation as well as rocks of the Goose Tickle Group. The limestones are recrystallized to a medium crystalline marble. The succession outcrops in a footwall structural window through the Rocky Pond Thrust. Upward the Table Point Formation, limestones are dominated by argillaceous and dolomitic nodular and thin bedded limestones as at Stop 2.5. These rocks are overlain by black slates of the Goose Tickle Group that occur in a small outcrop high on the bank to the west of the main outcrop.

Two fabric are visible in the succession. The limestones exhibit a prominent foliated fabric with augen of dolostone and chert associated with C-S fabrics and recumbent folds that indicate an early northwest-verging deformation associated with the thrusting. A strong stretching lineation trends 295° to 310° on the D1 foliation. A northwest-dipping cleavage crenulates and deforms the early fabrics. This D2 structure is axial planar to the main folds that deform the stack and its footwall into a series of northeast-trending, principally northeast-plunging folds, the latter are generally interpreted as Acadian structures, The timing of the thrusting is interpreted as part of a Salinic phase of deformation by Cooper *et al.* (2001).

Drive northeast to the entrance to the Pikes Brook access road and drive to the large aggregate pit just south of Pikes Brook The next two stops are optional.

Stop 2.7 - Pikes Brook thrust, the large pit is littered with boulders of a pink, orange to cream coloured dolostone of the Petit Jardin Formation, Port au Port Group that form the hangingwall of the thrust at this locality. Locally to the southwest, ribbon limestones of the Reluctant Head Formation mark the sole of the thrust. The dolostones tend to be heavily fractured in comparison to rocks of the footwall which are foliated marbles of the Ordovician Costa Bay Member to Table Point Formation. The marbles carry a prominent stretching lineation trending northwest. The thrust is now steepened to near vertical as are most of the thrusts in the hinterland part of the stack.

Stop 2.8 - Drive across Pikes Brook and take the left fork to follow the brook eastward for about 5 km. The last of the shelf rocks are past at a prominent shear zone about 1.5 km east of the bridge. The zone is characterized by a pelitic marble mylonite which displays complex interference folds and locally hosts a stretching lineation. Southeast of the mylonite zone phyllites/pelites, ribbon limestones with some limestone conglomerates dominate a new terrane mapped as the Breeches Pond Formation of the Mount Musgrave Group by Cawood and Van Gool (1992) but believed to more highly deformed and metamorphosed Pinchgut Lake Formation by Knight (1997). The strata are host to at least 3 and perhaps 4 deformations; phyllites are replaced by pelites and marbles become increasingly crystalline as the metamorphic grade increases from west to east where they reach greenschist grade.

Return to TCH by the same route and turn towards Corner Brook. As we approach Pinchgut Lake we will pass a steep dipping contact between Ordovician shelf carbonates of the Blue Pond Stack and phylites and ribbon limestones of the Pinchgut Lake Formation. Travel 3 km past the contact to long roadcut on the north side of TCH.

Stop 2.9 - Goose Tickle Group.

The Goose Tickle Group in the roadcut consists of grey slates with green grey sandstones. Grading in thenorthwest dipping sandstone beds indicate they are overturned. The main cleavage is carries a crenulation of a later cleavage. The Goose Tickle rocks are interpretated to form the footwall to the Pinchgut Lake Thrust, which is exclusively formed of rocks of the Pinchgut Lake Formation.

Proceed northeast on TCH to roadcut just before the turnoff north to Loggers School Road.

Stop 2.10 - Pinchgut Lake Formation.

The succession here is overturned to the southwest and cut by a north-trending, west-dipping cleavage. The succession youngs to the east and consists of cleaved shales, calcareous argillites and ribbon limestones interbedded with some resedimented grainstones and a number of thick limestone conglomerates. The latter include dolomite matrix supported types to those with matrices rich in oolites and quartz sand.

Continue east 9.5 km on the TCH to the great bend road cut above Corner Brook.

Stop 2.11 - Carboniferous paleo-cave.

The Middle Ordovician Table Point Formation which is in fault contact with Cambrian dolostones in the long road cut is cut by several high-angle faults that formed the locus of calcite vein systems and also a large vertical Carboniferous paleo-cave that is filled by red sediments. The faults trend approximately east-west, and commonly display oblique slickensides. The faults are common throughout this area. Note the limestone rubble in the base of the cave, the solution sculptured walls, discontinuity surfaces in the cave fill and sagging of the stratification. Similar paleo-caves and localized pockets of basal Carboniferous conglomerate lying unconformably upon the E–O carbonate terrane and across some of the areas major faults occur throughout the Corner Brook region. This implies that much of today's topography is an exhumed Carboniferous landscape when the area was hot and semi arid.

Proceed 2 km north along TCH to large roadcut beyond the access road from Massey Drive and Corner Brook.

Stop 2-12 - A late thrust placing Table Point Formation above steeply dipping polydeformed Taconian allochthonous sediments.

Table Point Formation limestone dipping to the west is thrust above grey phyllitic sediments of the Humber Arm Allochthon. The thrust is offset by east-trending wrench fault associated with an array of calcite veins. The thrust is possibly a late structure since Table Point Formation is overlain by the phyllites on the west side of the TCH.

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4.4-4.7 km - Shallow water carbonate rocks of the upper part of the St. George Group outcrop in several exposures along Route 463 at the west end of Port au Port Peninsula. The sucrosic dolostone with slight porosity belongs to the Catoche Formation, underlying the Aguathuna Formation. At the far end of the section, grey limestones belonging to the Catoche Formation are exposed. Note the present day karst scenery that the road is passing through; as you proceed around a large bend and begin climbing a hill, observe the large, rounded boulders infilling stream channels on the hillside to the left of the road. Perhaps an analogy for the karst infill at 2.8-2.9 km?

The succession yields a new, fairly abundant and diverse shelly fauna. The fauna occurs within metre-scale parasequences of open shelf muddy carbonates overlain by grainy carbonates that are commonly rich in small oncolites, and which are assigned to the Costa Bay Member of Catoche Formation (Fig. 32). Exquisitely-preserved graptolites accompany the shelly fauna in the upper 20 m of the member, an interval marked by a shoaling sequence of subtidal muddy carbonate to cross bedded, now dolomitized, grainstone.

Two faunas are recognized in the rubbly, yellow weathering, thin bedded, oncolitic dolomitic limestone of the Costa Bay Member. The lower *Gignopeltis rarus* fauna — based on the presence of *Gignopeltis rarus* (Billings, 1865) — Boyce *et al.* (2000) correlated with the Late Canadian (Cassinian) *Gignopeltis rarus* Zone of Boyce (1997a). The higher *Cybelopsis speciosa* fauna includes a rich shelly macrofauna; based on the presence of *Cybelopsis speciosa* Poulsen, 1927, *Pomatotrema* sp. cf. *P. semiconvexum* (Poulsen, 1927) and *Didymograptellus bifidus* (Hall, 1858), Boyce *et al.* (2000) correlated the *Cybelopsis speciosa* fauna with that of the lithologically similar Nunatami Formation of western North Greenland.

Isoteloides polaris Poulsen, 1927 is common to the Nunatami Formation of western North Greenland and the *Pseudocybele nasuta* Zone (Zone J) of western Utah (Boyce *et al.*, 2000, pages 123, 124). Consequently the *Cybelopsis speciosa* fauna of the Costa Bay Member also correlates with the *Pseudocybele nasuta* Zone (Zone J). Williams *et al.* (2000) correlated the fauna with that of the middle part of Bed 11 (*D. bifidus* Zone) of the Cow Head Group (Williams and Stevens 1988).

The abundant and diverse faunas in shoaling subtidal limestone parasequences of the Costa Bay Member support open shelf marine setting seaward of a major grainstone barrier complex (Fig. 33; Boyce *et al.*, 2000). The importance of graptolites at the top of the Costa Bay Member may suggest an important oceanic flooding event marked the shelf at the transition from the open-shelf Costa Bay to the broad development of peritidal flats preserved in the Aguathuna Formation.

Peritidal cyclic carbonates of the Aguathuna Formation yield mainly a mixed molluscan fauna of gastropods, including silicified opercula — *Ceratopea unguis* Yochelson and Bridge, 1957 and *Teiichispira odenvillensis* (Butts, 1926), according to Rohr *et al.* (2000) — and cephalopods, although grainstone beds contain as yet undetermined brachiopods and trilobites.

Beyond this point the road passes through a series of limestones and dolostones of the St. George Group. Points of interest include a spectacular view over the westernmost tip of the Port au Port Peninsula at 6.0 km and Carboniferous karst infill deposits at 8.7 km and 9.7 km, the latter including some boulders over 2 metres in diameter. The site of the exploration well Port au Port #1 drilled by Hunt Oil Company and Pan Canadian in 1994-95 is on the left of the road at 11.1 km, marked by a large well head valve. The well was spudded in the Catoche Formation; fragments of fossiliferous limestone belonging to this unit are present at the site. Oil was encountered in this well, within cavernous porosity in the early Ordovician Aguathuna and Watts Bight formations (see Cooper *et al.* 2001 for summary); Canadian Imperial Venture plans to begin production from the well this year.

Continue along the road to the bottom of the long hill; opposite the community boundary sign for Cape St. George is the site of the Talisman *et al.* Long Range A-09 exploration well drilled by Talisman Energy Inc. and associates in the first half of 1996; this well was declared dry, as was the 1996 offshore St. George's A-36 well drilled by Hunt Oil Company and PanCanadian Petroleum Company some 5 km southwest of Cape St. George.

From here, we will return to Deer Lake via Stephenville.

DAY 4. PORT AU PORT PENINSULA

STOP 4-1. PICADILLY QUARRY

Location
Follow Highway 463 along the northern shore of the Port au Port Peninsula until the Provincial Park at Picadilly is reached. Another kilometer beyond this point is a disused quarry on the left of the road.

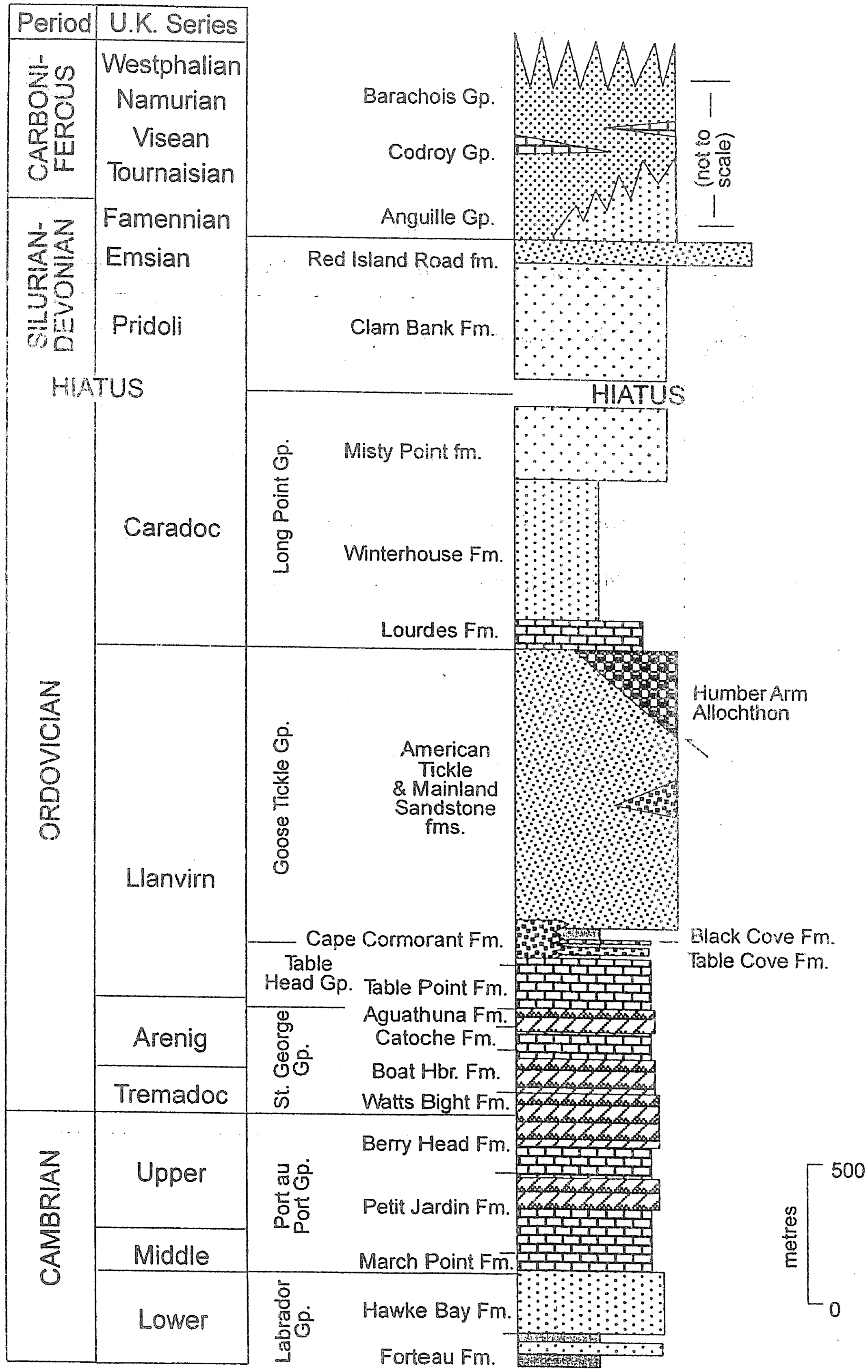
Safety notes
Be careful of loose boulders in this sporadically worked quarry.

Description
In Picadilly Quarry (also referred to in some previous publications as West Bay Centre Quarry) some 15 m of interbedded grey limestones and shales of the Table Cove Formation (Stenzel *et al.*, 1990) are overlain by a few meters of black shale and sandstone of the Black Cove and American Tickle formations of the Goose Tickle Group. The locality has long been known for its abundant, well preserved graptolite fauna (*e.g.*, Schuchert and Dunbar, 1934; Whittington and Kindle, 1963; Morris and Kay, 1966); it was collected in detail by Finney, who outlined the general sequence and assemblage (Finney and Skevington, 1979) but did not give any systematic taxonomic treatment to the fauna with the exception of a couple of short papers related to specific taxa (Finney and Chen, 1984). More recently, the quarry has been recollected and the fauna described in detail by R. Taylor (1996) and has been examined critically in light of its biostratigraphic significance on a global scale by J. Maletz (*e.g.*, Mitchell and Maletz, 1994). These authors conclude that the fauna, which is a diverse assemblage including *Archiclimacograptus* spp., *Cryptograptus schaeferi*, *Glossograptus* spp., *Bergstroemograptus crawfordi*, *Pseudotrigonograptus ensiformis*, *Isograptus forcipiformis* and *Nicholsonograptus fasciculatus* among others, indicates a Darriwilian (Da) 3 age (*i.e.*, middle Llanvirn).

In 1993, Boyce (unpublished) collected a shelly macrofauna from lime grainstones and mudstones of the Table Cove Formation here, typical of the *Cybelurus mirus* Zone of Boyce (1997a).

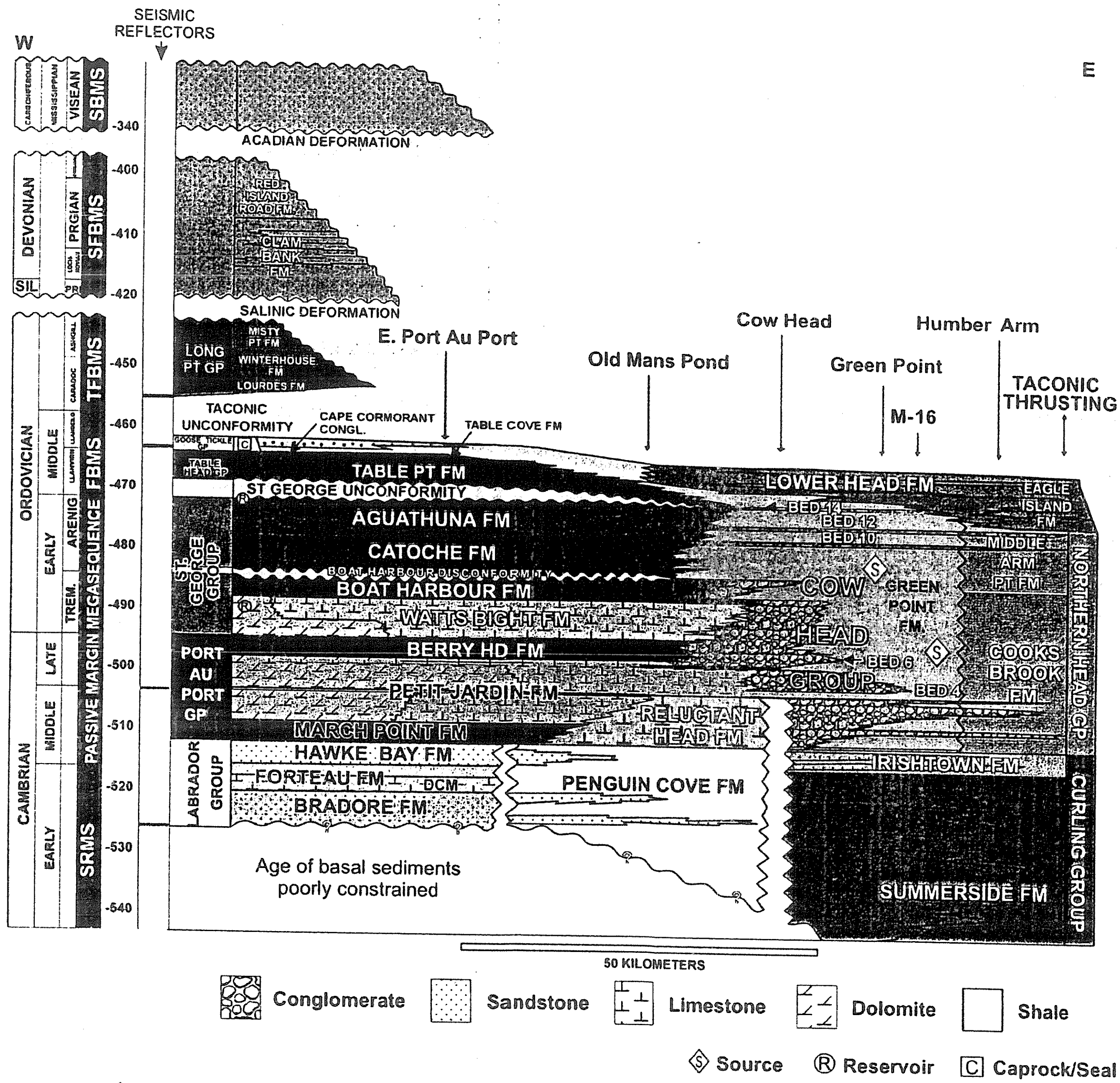
In the main part of the quarry, the most abundant graptolites are found in black, calcareous shales towards the top of the section nearest the road, both in the main walls and in the isolated "pillar". In order to examine the Black Cove and American Tickle formations it is necessary to follow the small trackway on the right-hand (west) side of the quarry for ca. 50 m uphill. The Black Cove Formation (the basal unit of the Goose Tickle Group) is composed of non- calcareous black shale containing even more abundant graptolites than the Table Cove Formation. It is, however, very friable and weathers easily, making extraction of anything other than small rhabdosomes extremely difficult. The base of the American Tickle Formation is marked by deposition of grey-green sandstones; these have been interpreted variously as belonging to a turbidite or contourite sequence, but certainly were deposited along the slope. It contains rare, poorly preserved diplograptid graptolites belonging to the same taxa as the underlying units. A few metres above the base is a small, carbonate clast conglomerate; this is a debris flow conglomerate assigned to the Daniel's Harbour Member of the Goose Tickle Group.

FIGURE 1



Paleozoic stratigraphy in western Newfoundland.

FIGURE 2



Chronostratigraphic summary diagram of western Newfoundland Paleozoic strata. Lithostratigraphic units are colored, and the ornamentation indicates the dominant lithology. The age ranges of the megasequences defined are shown to the right of the geological stages; SRMS = synrift megasequence; FBMS = flexural bulge megasequence; TFBMS = Taconic foreland basin megasequence; SFBMS = Salinic foreland basin megasequence; SBMS = successor basin megasequence; DCM = Devil's Cove member of the Forteau Formation. Dating of the strata is based on paleontological data from James and Stevens (1986), Botsford (1987), S. H. Williams et al. (1987), S. H. Williams and Stevens (1988), Stenzel et al. (1990), Knight and Cawood (1991), Knight et al. (1991), Stait and Barnes (1991), Cowan and James (1993), and Burden and Williams (1995, 1996). The time scale used is that of Tucker and McKerrow (1995). Additional stratigraphic data from Schuchert and Dunbar (1934), Betz (1939), Weitz (1953), Stevens (1965), Brueckner (1966), Klappa et al. (1980), Hiscott et al. (1984), H. Williams et al. (1985a, b), Botsford (1987), and Knight and Boyce (1991).

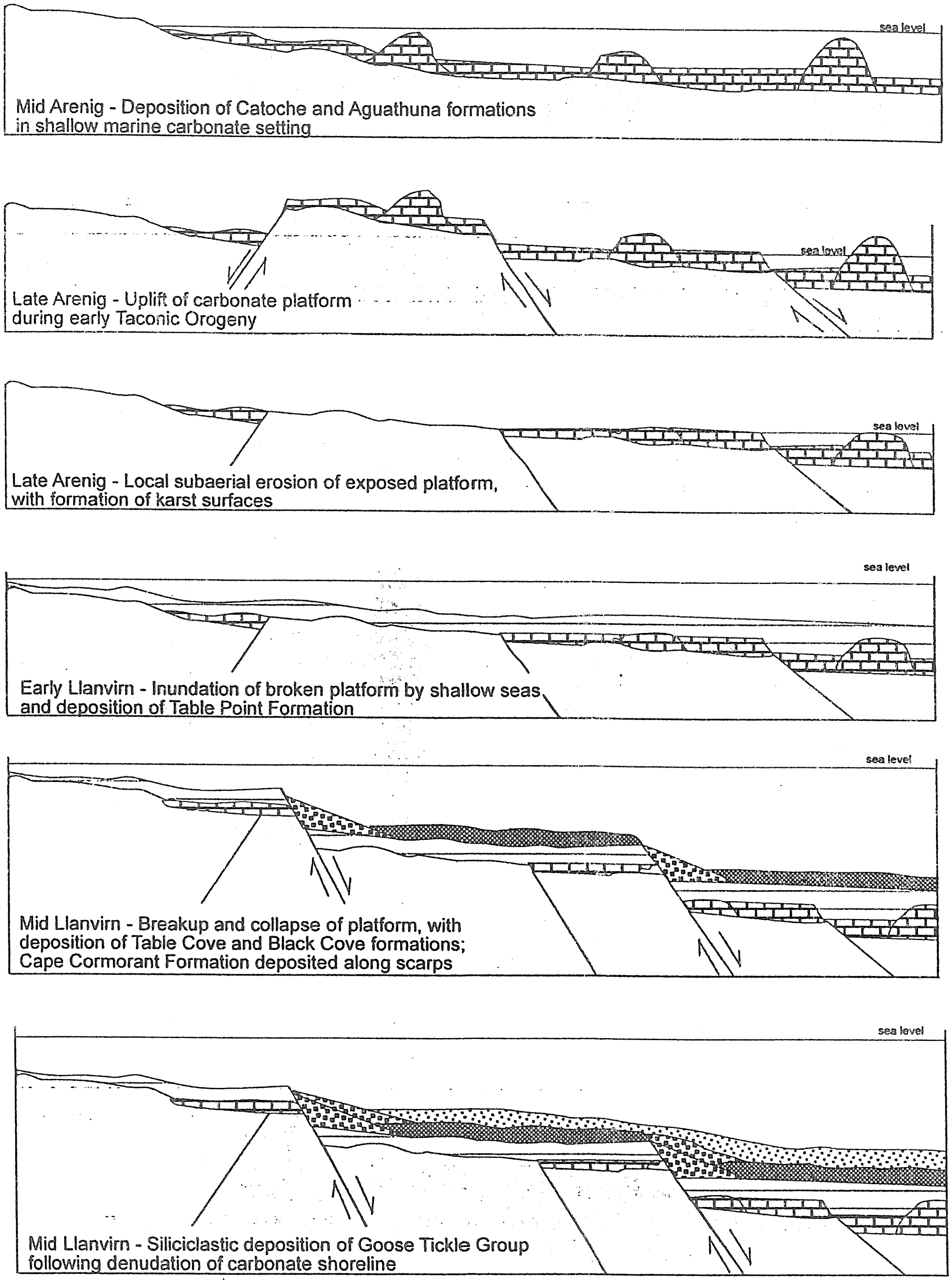
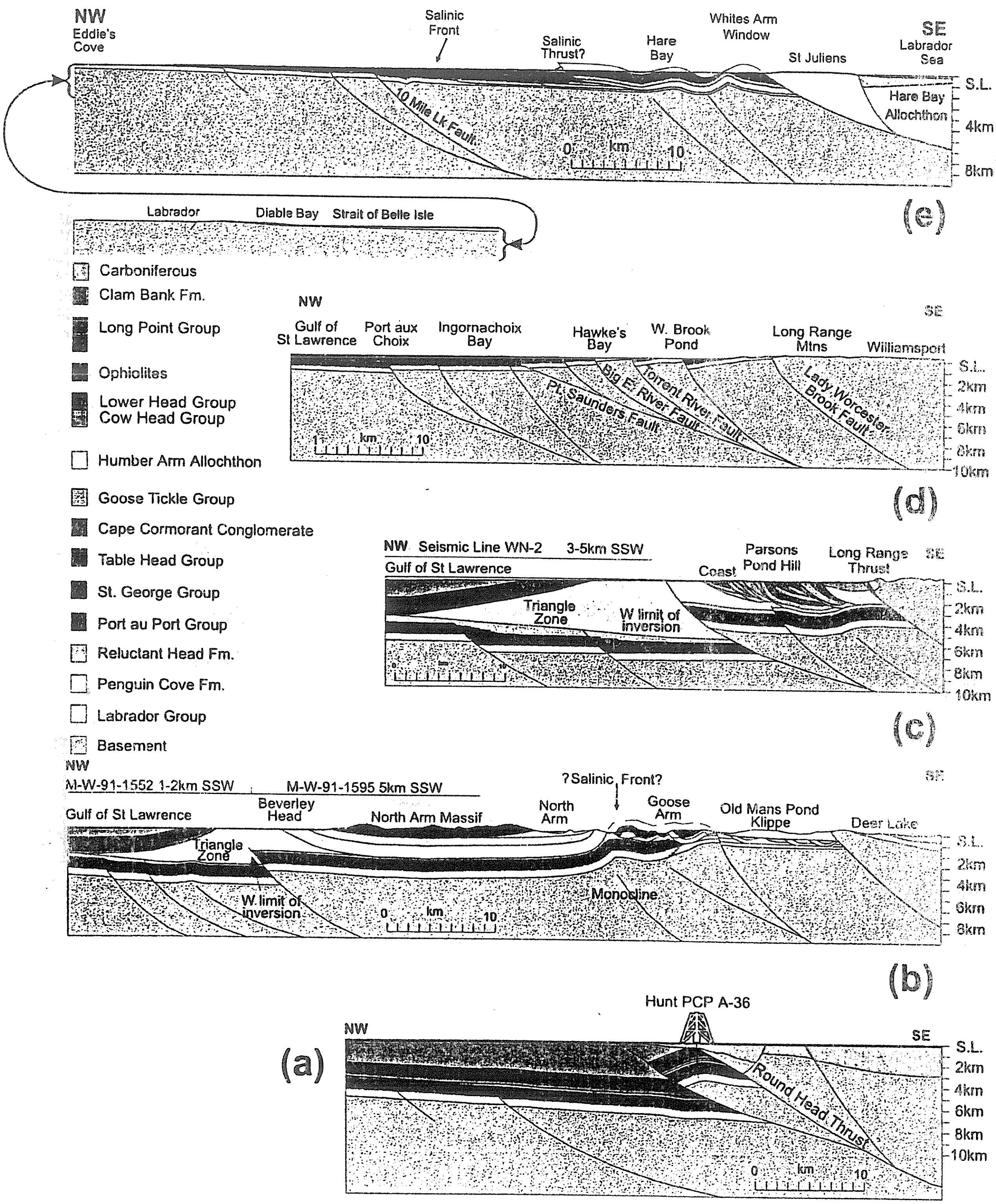


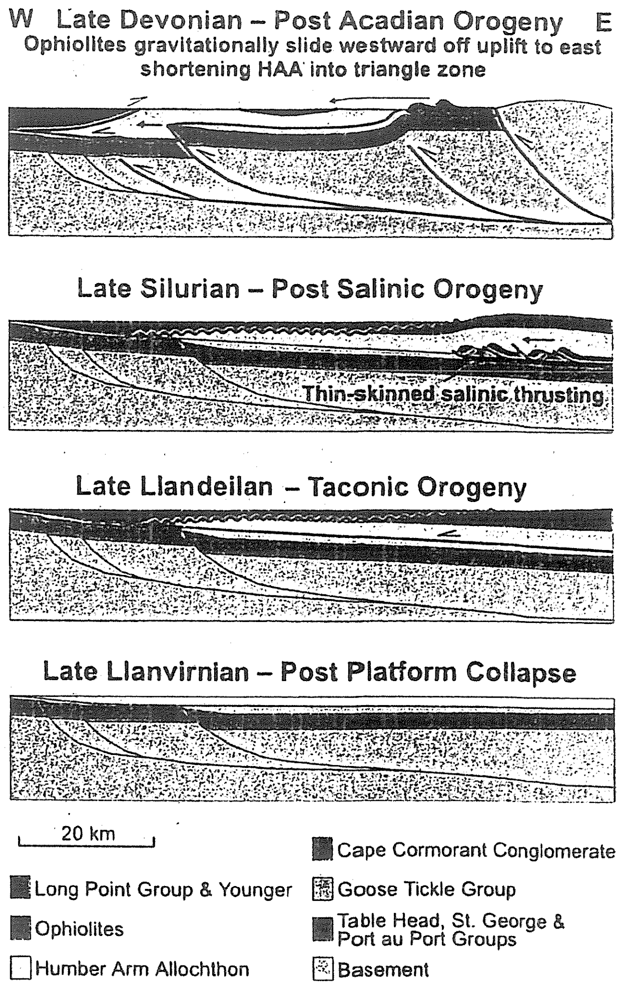
Figure 3. Development and collapse of Ordovician carbonate platform in western Newfoundland.

FIGURE 4



. Regional cross sections to illustrate structural style variations; for locations see Figures 1 and 5. The cross sections are described in the text.

FIGURE 5



Conceptual model of structural evolution of the Humber zone (modified from Knight and Cawood, 1991).

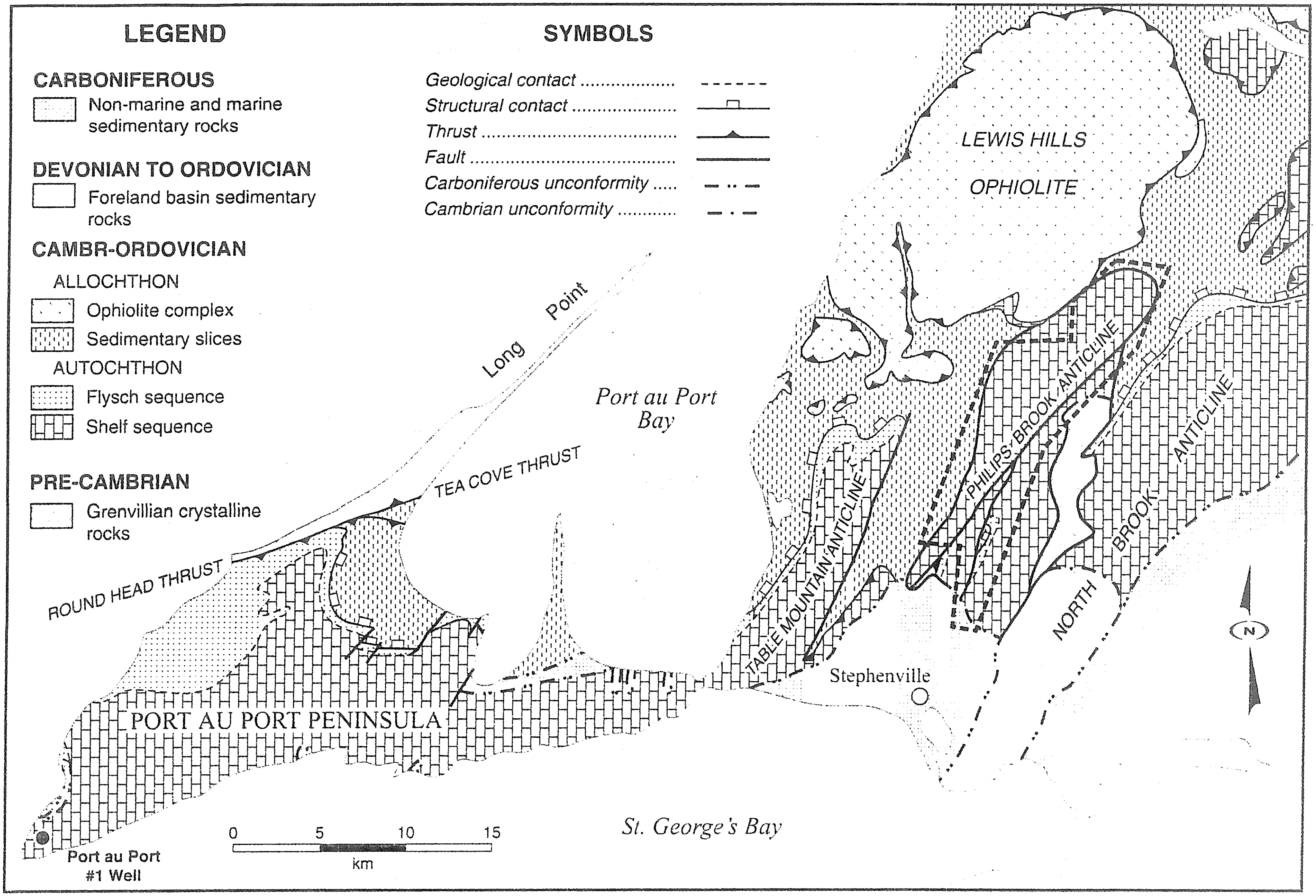


FIGURE 6

Simplified regional geological map of the Port au Port and Stephenville areas showing the main geological terrains and outlining the map area of the Phillips Brook anticline (based on Williams and Cawood, 1989).

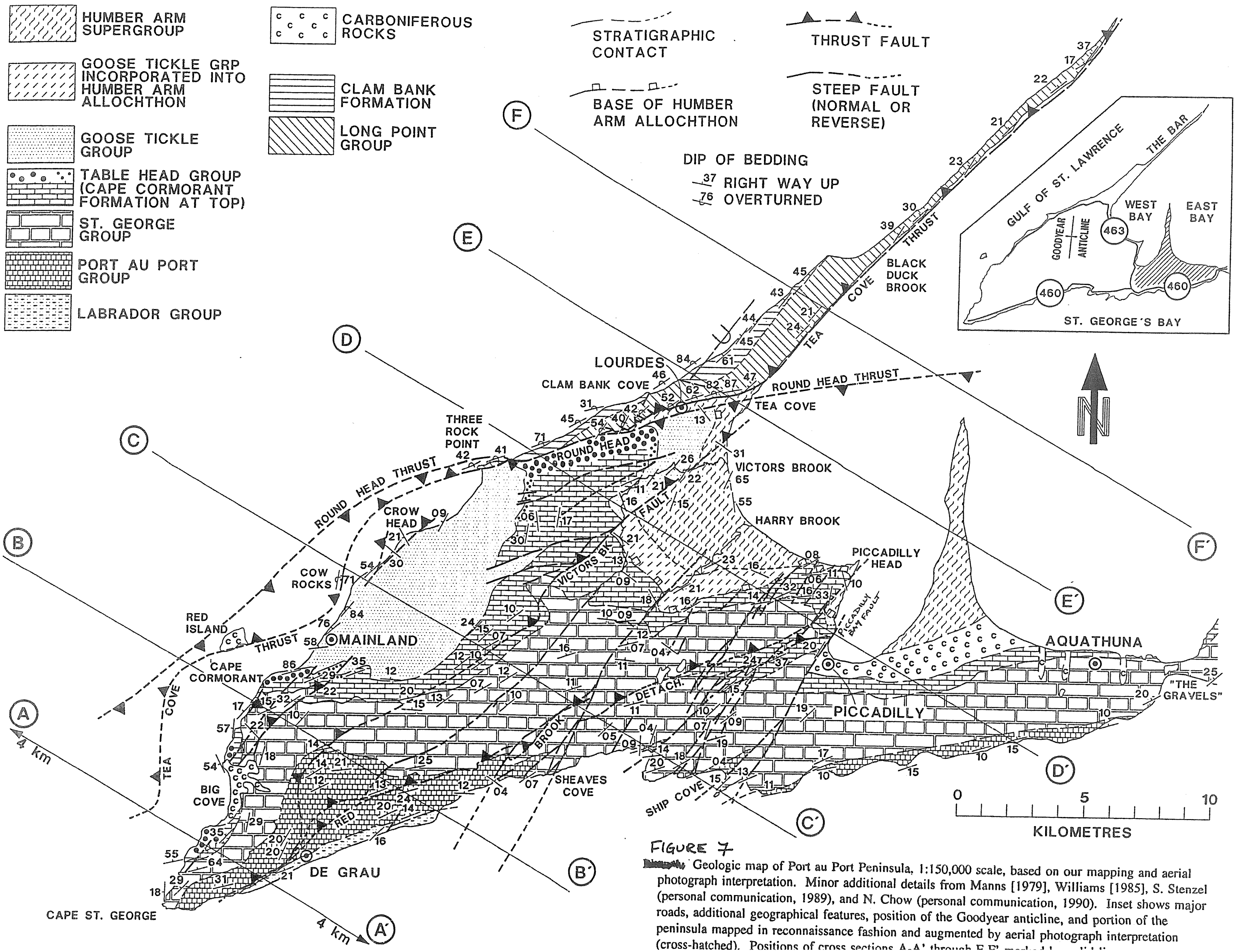
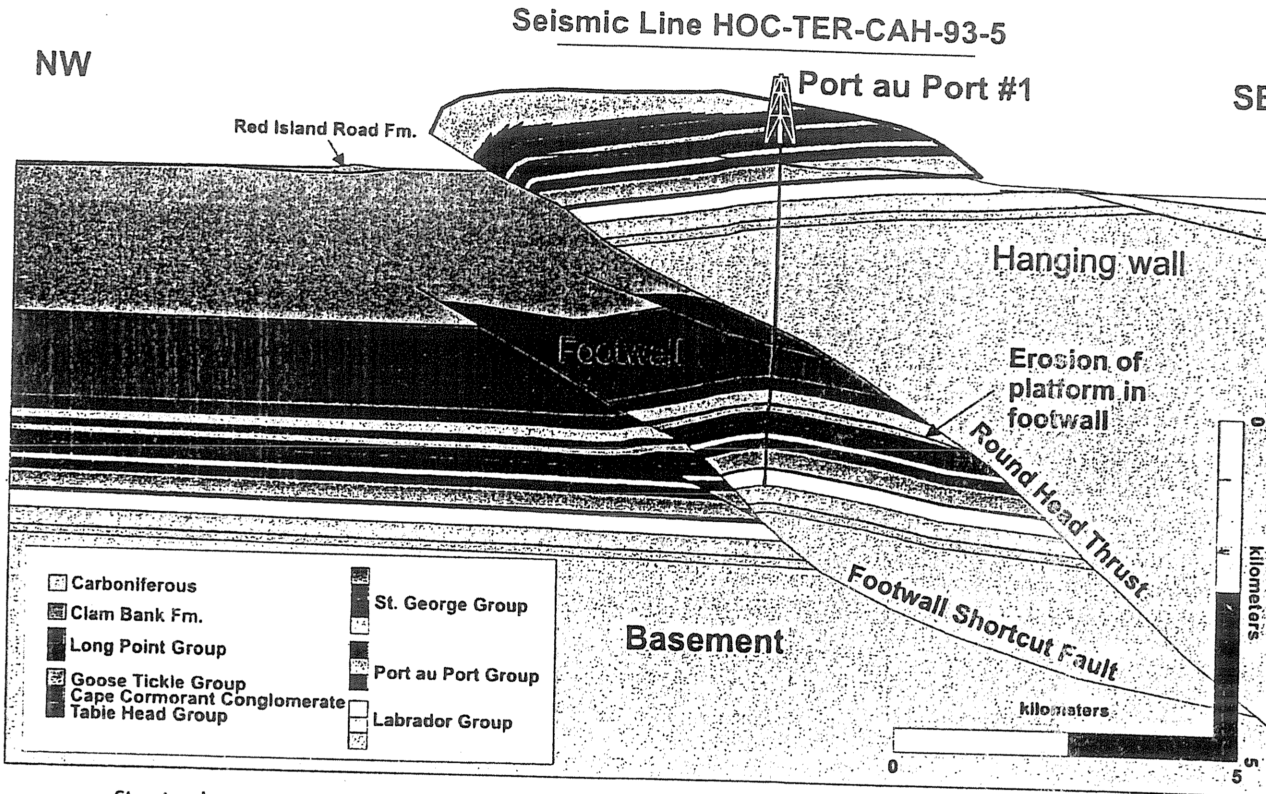
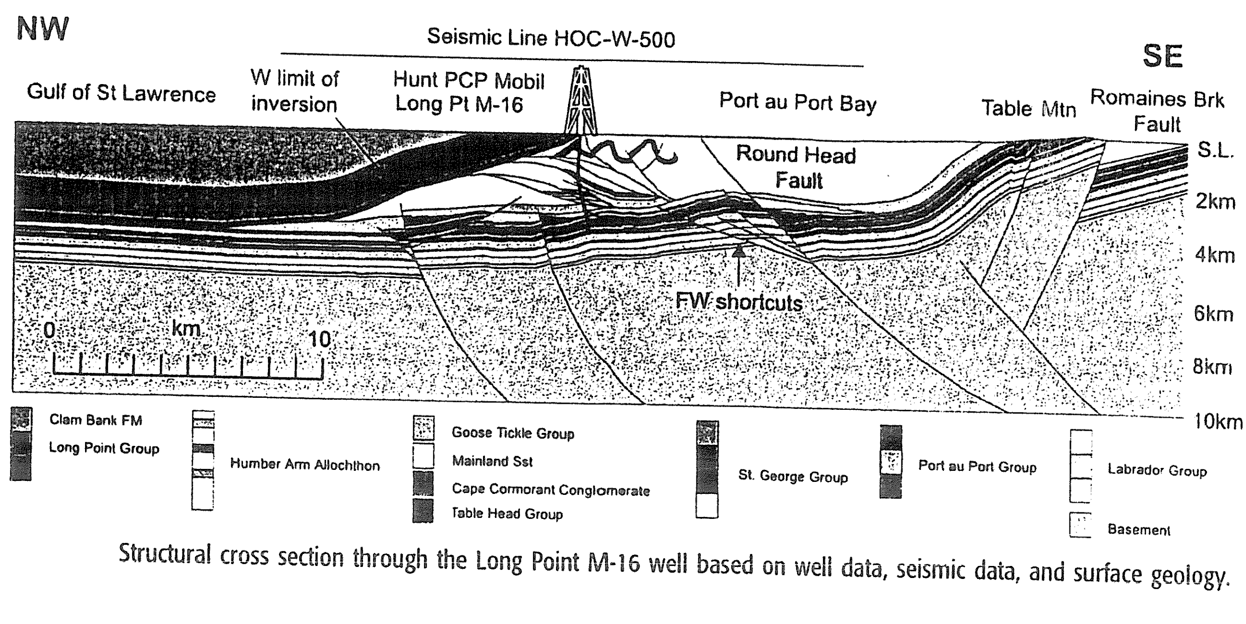


FIGURE 7 Geologic map of Port au Port Peninsula, 1:150,000 scale, based on our mapping and aerial photograph interpretation. Minor additional details from Manns [1979], Williams [1985], S. Stenzel (personal communication, 1989), and N. Chow (personal communication, 1990). Inset shows major roads, additional geographical features, position of the Goodyear anticline, and portion of the peninsula mapped in reconnaissance fashion and augmented by aerial photograph interpretation (cross-hatched). Positions of cross sections A-A' through



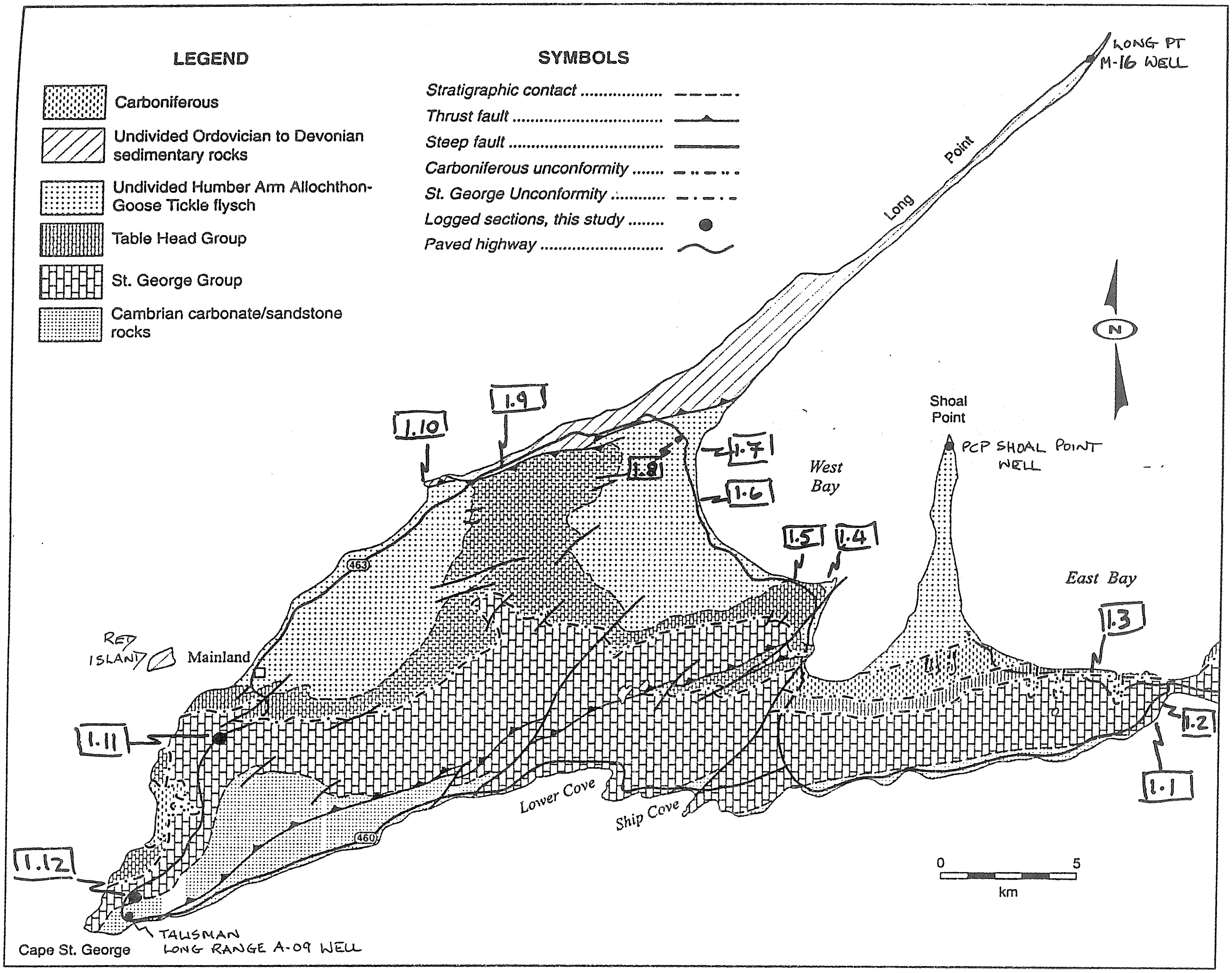
Structural cross section through the Port au Port 1 well based on surface geology, seismic data, and dip and formation data from the well. Line location in Figure 5.

FIGURE 8



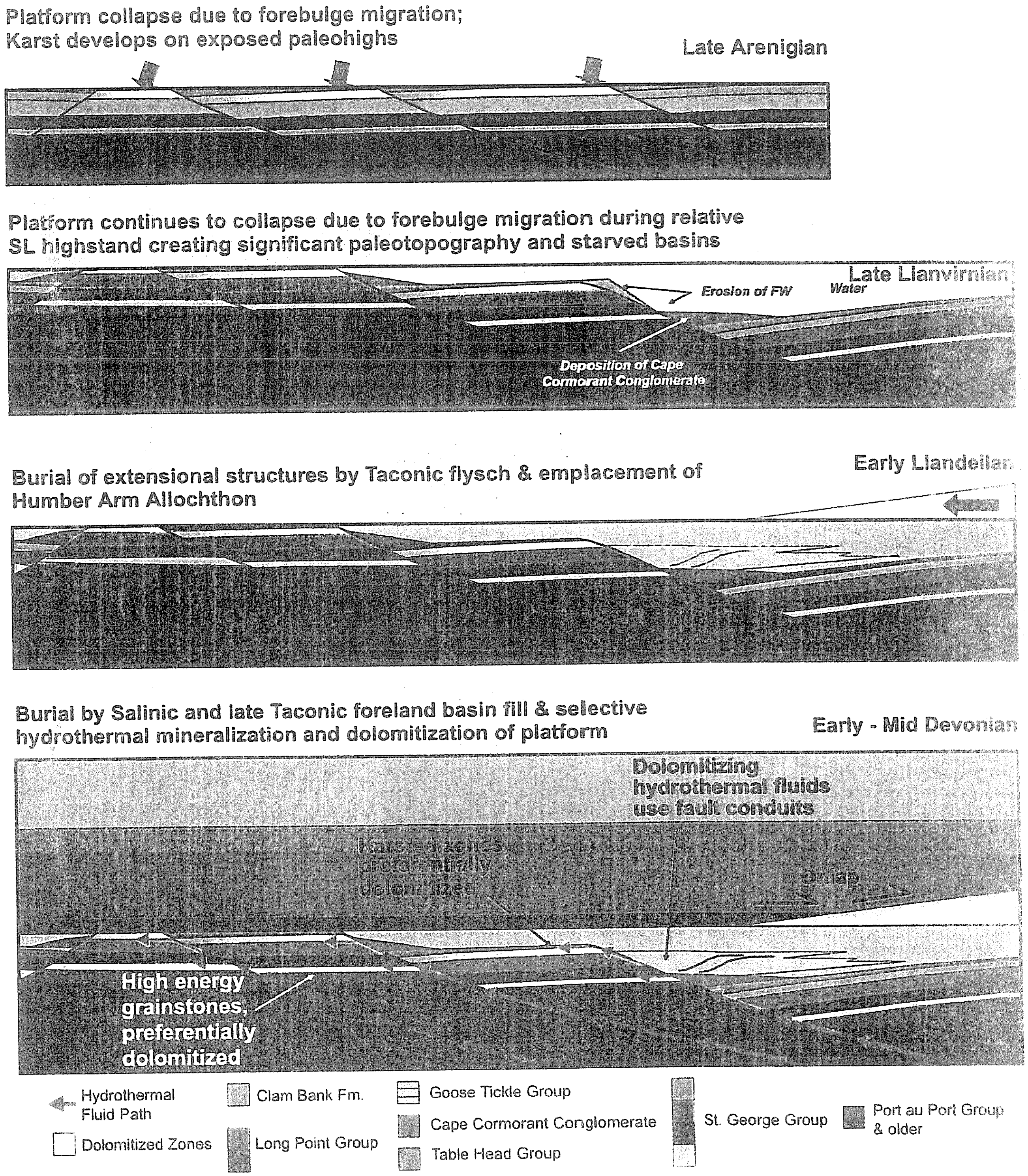
Structural cross section through the Long Point M-16 well based on well data, seismic data, and surface geology.

FIGURE 9



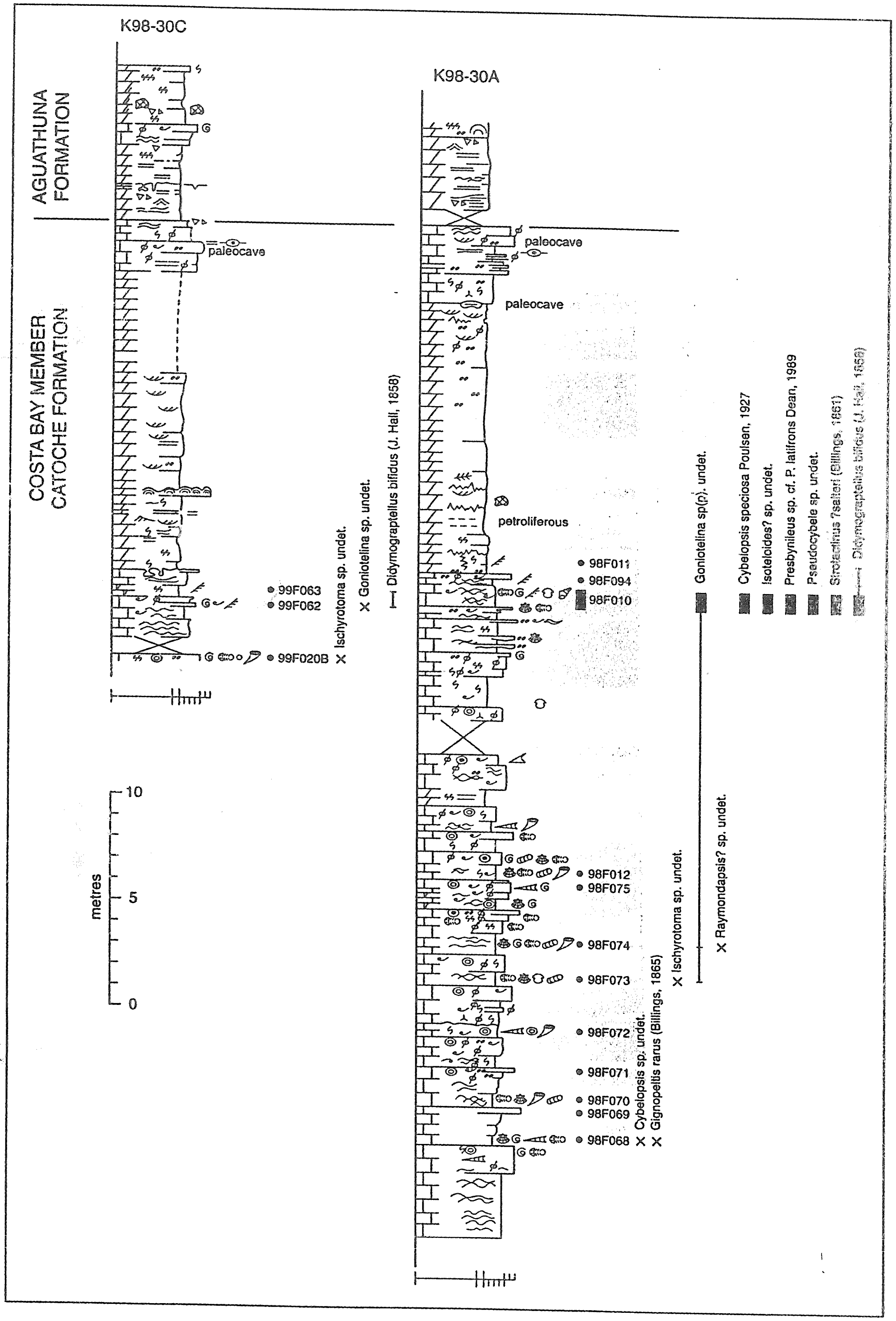
. Geological map of the Port au Port Peninsula showing the location of the new section at the western end of the Peninsula and other important sections through the Costa Bay Member, Catoche Formation. Map based on Stockmal and Waldron (1993).

FIGURE 10



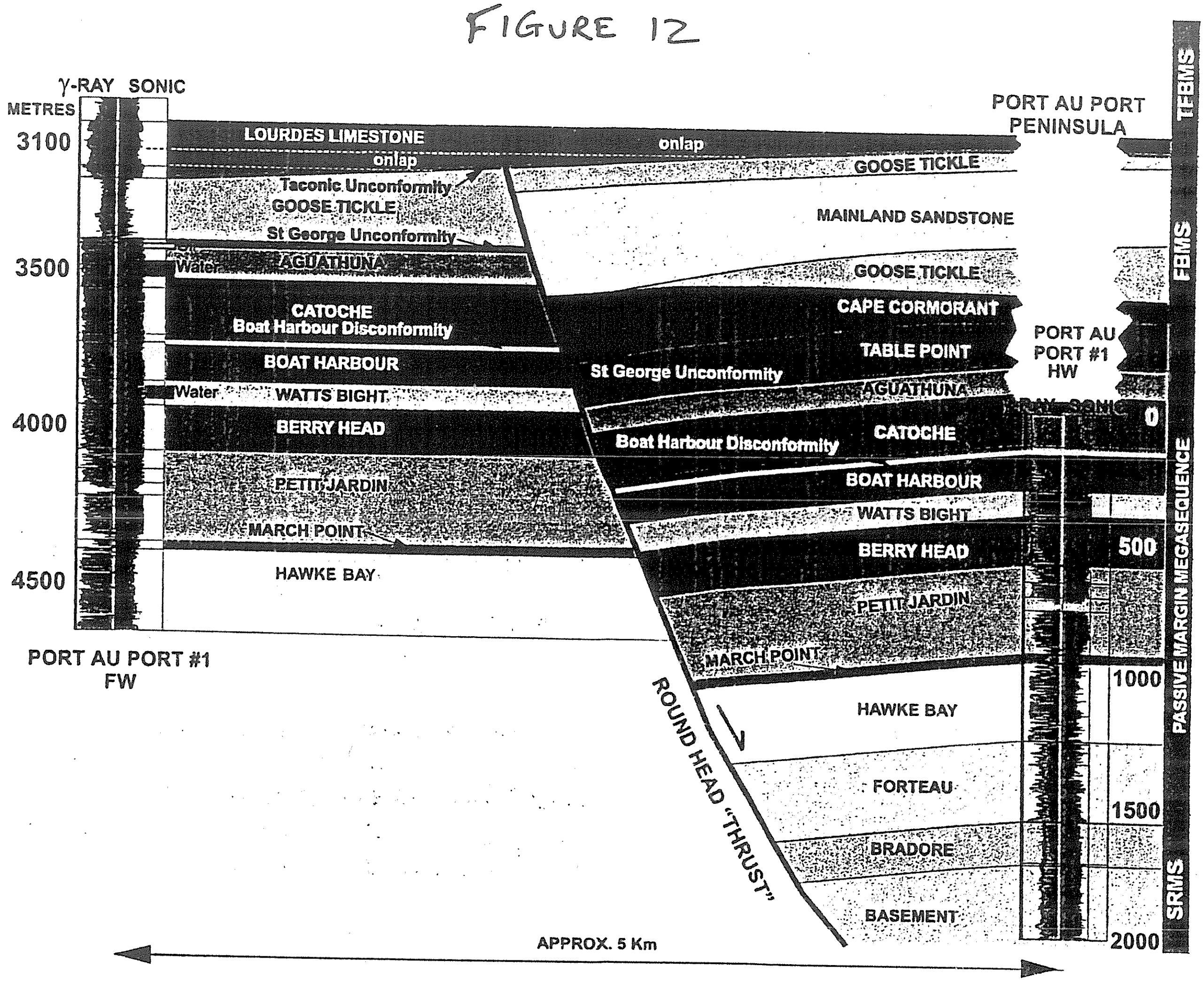
Model of reservoir development based on data from the wells and outcrop studies; see text for discussion.

FIGURE 11



Ranges of trilobite and graptolite taxa in the Costa Bay Member, Catoche Formation, section along Route 463, western Port au Port Peninsula. STOP 1.11

FIGURE 12



Stratigraphic reconstruction of the Round Head fault at end Lourdes time. Logs from the footwall part of the Port au Port 1 well have been used without modification. Logs from the hanging-wall part of the Port au Port 1 well were corrected for 40°NW dips to create true stratigraphic thickness logs prior to inclusion in the correlation. The Port au Port 1 well spudded in the Catoche Formation, and the thickness of the overlying units has been reconstructed using published data from the Port au Port Peninsula outcrops (Stenzel et al., 1990; Knight et al., 1991; Stait and Barnes, 1991; Quinn, 1995). See Figure 2 caption for explanation of abbreviations; major unconformities are shown as red lines.

FIGURE 13

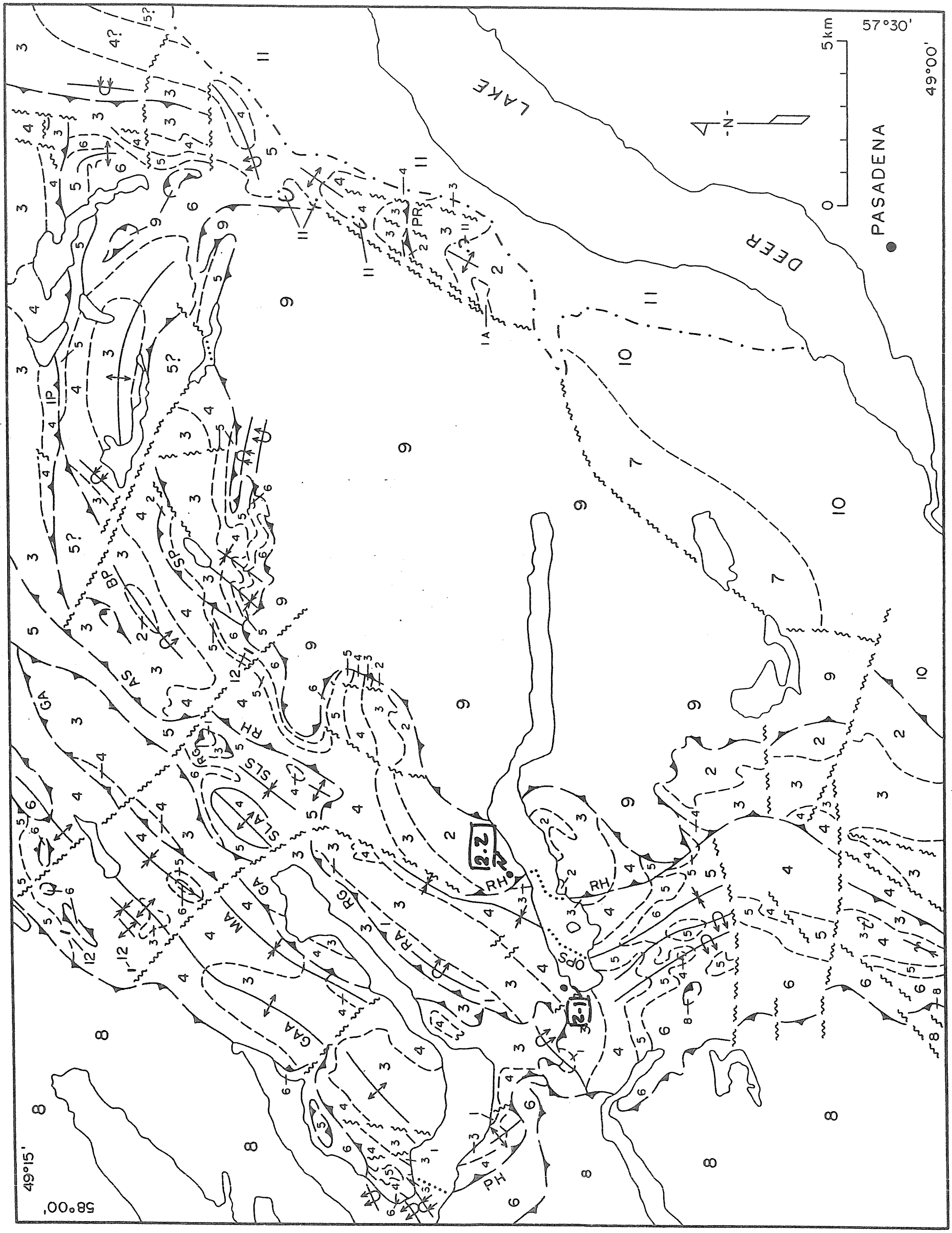


FIGURE 13

ROCKS OF UNKNOWN AGE

12 *Mafic dykes*

CARBONIFEROUS

11 *Deer Lake Group*

ALLOCHTHONOUS ROCKS

10 *Mount Musgrave Group (Precambrian to Cambrian?)*

9 *Old Man Pond Allochthon (Hadrynian to Ordovician?)*

8 *Humber Arm Allochthon (Hadrynian to Ordovician?)*

7 *Hughes Lake Complex (Hadrynian)*

PARAUTOCHTHONOUS ROCKS

ORDOVICIAN (Lower to Middle)

6 *Goose Tickle Group*

5 *Table Head Group*

4 *St. George Group*

CAMBRIAN (Middle to Upper)

3 *Port au Port Group*

2 *Reluctant Head Formation*

1 *Penguin Cove Formation*

1A *Psammite and pelite equivalent of Penguin Cove Formation?*

LEGEND

— — — — *Stratigraphic contact*

—·—·— *Unconformity*

~~~~~ *Fault*

Thrust (teeth indicate hangingwall or hangingwall and dip; tine indicates dip if thrust is folded)

Fold axes (upright, recumbent)

Fold axes (now downward facing due to refolding)

PH *Penguin Head thrust*

GA *Goose Arm thrust*

RG *Raglan Head thrust*

RH *Reluctant Head thrust*

AS *Alder Steady thrust*

SP *Seal Pond thrust*

IP *Island Pond thrust*

PR *'Pye's ridge' thrust*

GAA *Goose Arm anticline*

RA *Raglan Head anticline*

BP *Beaver Pond anticline*

SLA *Sugar Loaves anticline*

SLS *Sugar Loaves syncline*

MA *Middle Arm syncline*

OPS *Old Man Pond syncline*

Simplified geological map of the Pasadena map area that shows the distribution of major stratigraphic subdivisions and geological structures in the parautochthonous belt (based on Knight and Boyce, 1991; Knight, 1992, unpublished data).
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FIGURE 14

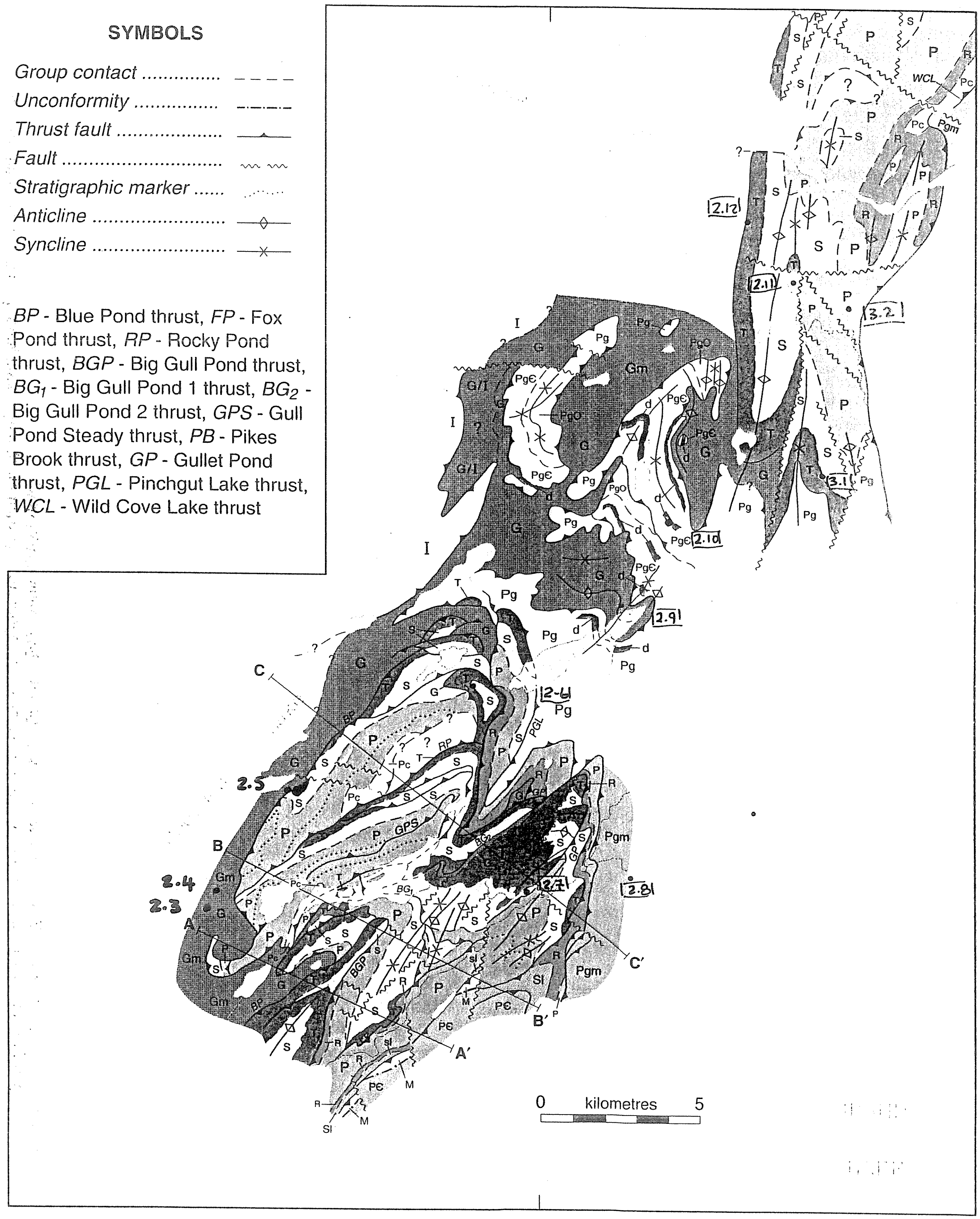
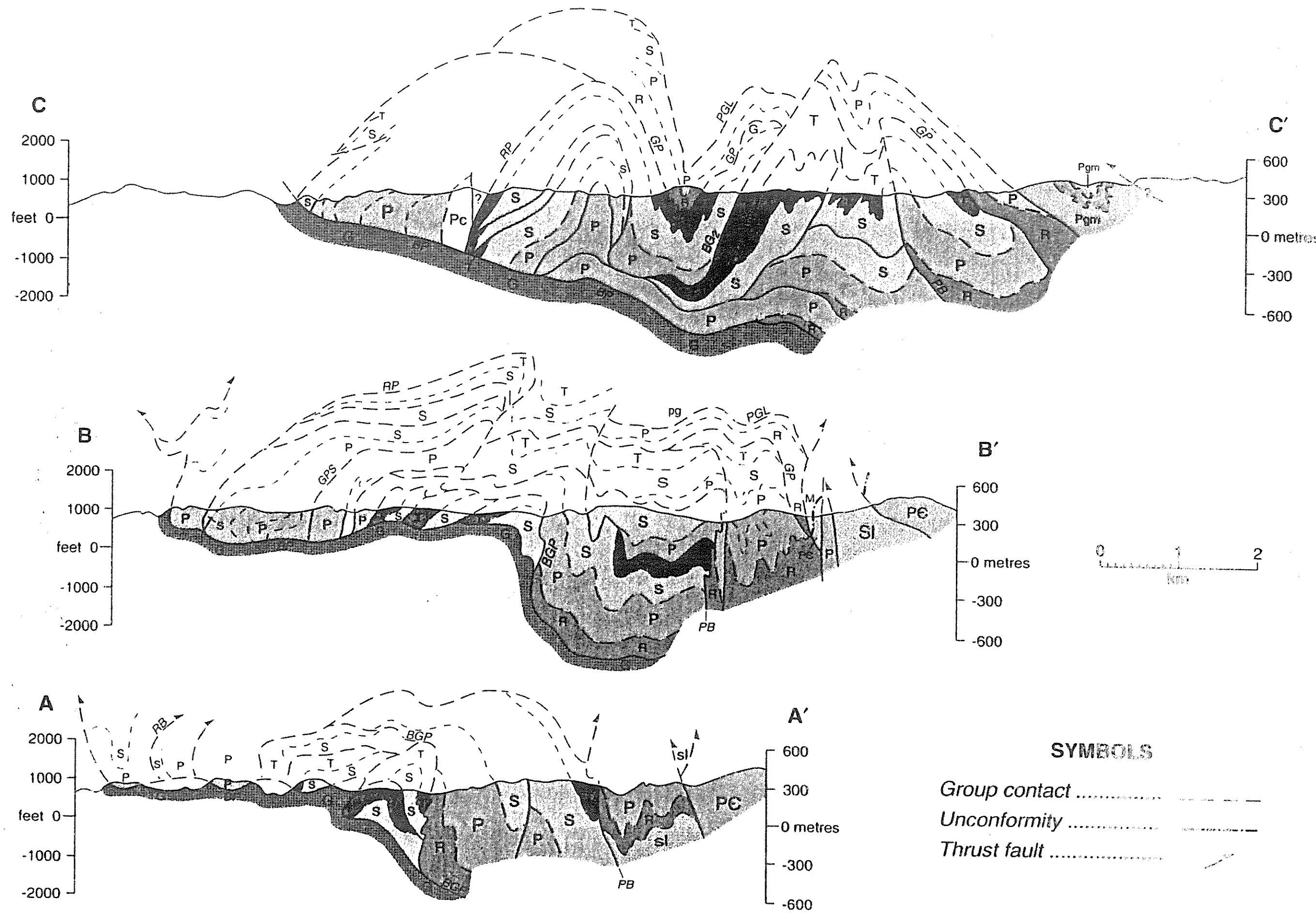

SYMBOLS
Group contact
Unconformity
Thrust fault
Fault
Stratigraphic marker
Anticline
Syncline
BP - Blue Pond thrust, FP - Fox Pond thrust, RP - Rocky Pond thrust, BGP - Big Gull Pond thrust, BG1 - Big Gull Pond 1 thrust, BG2 - Big Gull Pond 2 thrust, GPS - Gull Pond Steady thrust, PB - Pikes Brook thrust, GP - Gullet Pond thrust, PGL - Pinchgut Lake thrust, WCL - Wild Cove Lake thrust
0 kilometres 5
C
C'
B
B'
A
A'
2.12
2.11
3.2
3.1
2.10
2.9
2-6
2.5
2.4
2.3
2.7
2.8

FIGURE 14



Preliminary interpretative cross sections through the Blue Pond thrust stack; vertical exaggeration x 2.

FIGURE 14

LEGEND

DOMAIN 1

HUMBER ARM ALLOCHTHON

Cambrian

I — *Irishtown Formation (Curling Group): quartzitic metasandstone;* **G/I**, *grey slate and phyllite*

DOMAIN 2

Ordovician

G — Goose Tickle Group: *green-grey metasandstone, grey phyllite, dolomitic siltstone, minor ribbon limestone and dolostone;* **Gm,** *disrupted formation to melange-like*

DOMAIN 3A, 3C

Ordovician

G — GooseTickle Group: *grey slate, green-grey sandstone, siltstone, minor thin-bedded and conglomeratic limestone*

T — Table Head Group: *grey, bioturbated and stylonodular to stylo-thin-bedded limestone, argillaceous limestone, dolostone and dolomitic limestone in lower part*

S — St. George Group: *grey limestone and interbedded dolostone and limestone*

P — Port au Port Group: *pale-grey dolostone, argillaceous dolostone; dotted marker - oolitic and stromatolitic limestone interbedded with dolostone*

R — Reluctant Head Formation: *ribbon limestone, grey phyllite, minor limestone conglomerate, grainstone at top, locally dolomitized*

Pc — Penguin Cove: *thin-bedded quartzose sandstone and siltstone, nodular and thin-bedded limestone, grey and green-grey phyllite and slate*

Sl — Unnamed unit: *grey slate and phyllite*

DOMAIN 3B, DOMAIN 4

Cambrian – Ordovician

Pg — Pinchgut Lake Group: *grey and silver-grey phyllite, slate, calcareous and dolomitic phyllite, ribbon limestone, oolitic and quartzitic limestone, limestone conglomerate;*

Pg ϵ-Cambrian; Pg O -Ordovician;

d - marker of oolitic and quartzitic limestone, limestone conglomerate in Pg ϵ;

Pg m, micaceous phyllite, conglomeratic and crystalline grey marble (Breeches Pond Formation of Cawood and van Gool, 1994)

DOMAIN 5

Cambrian – Precambrian?

M — Mount Musgrave Group: *quarztitic psammite, green-grey to pink chloritic marble, pelite*

Precambrian

Pϵ — Grenvillian gneiss: *granitic gneiss, amphibolitic gneiss, micaceous schist*

KEY

BP - Blue Pond thrust, FP - Fox Pond thrust, RP - Rocky Pond thrust, BGP - Big Gull Pond thrust, BG1 -Big Gull Pond 1 thrust, BG2 - Big Gull Pond 2 thrust, GPS - Gull Pond Steady thrust, PB - Pikes Brook thrust, GP - Gullet Pond thrust, PGL - Pinchgut Lake thrust, WCL - Wild Cove Lake thrust

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