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TECTONOSTRATIGRAPHY OF AN EXHUMED BLOW ME DOWN BROOK FORMATION HYDROCARBON RESERVOIR, SLUICE BROOK, WESTERN NEWFOUNDLAND[1]

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ABSTRACT

Regional 1:50 000 mapping of sedimentary strata, north of the community of Fox Island River, shows a complex pattern of west-verging D_1 thrusts, broken by younger normal and reverse faults. Coastal exposures in this area are predominantly thick-bedded, fine- to coarse-grained conglomeratic, feldspathic and arkosic sandstone and shale of the Blow Me Down Brook Formation. In one particularly well-exposed locality, north of Sluice Brook, an extensive section of bituminous Blow Me Down Brook sandstone and shale apparently outlines a cross-section of a breached hydrocarbon reservoir that formed as an open, south-verging D_2 antiformal structure in the hanging wall of a folded F_1 thrust. The core of this D_2 antiform contains the footwall strata of the F_1 thrust. Here, refolded and faulted Northern Head Group limestone and shale form a blind, south-verging F_2 wedge, thrust into the F_1 fault zone. If hydrocarbons moved into these rocks after the D_2 antiform was created, then this points to a post-Taconic age for hydrocarbon generation and migration, and notably the first convincing evidence for Early Cambrian clastic reservoirs in western Newfoundland.

INTRODUCTION

For nearly 150 years, western Newfoundland and the adjacent Gulf of St Lawrence continues to present an appealing and yet very challenging exploration region (Henry, 1910; Baird and Snelgrove, 1953; Fleming, 1970; Eaton, 2004). Oil seeps, staining, and pyrobitumen are common features along the coast (Figure 1). As some of the best and clearest indicators for an active petroleum system, most of these hydrocarbon shows are associated with the transported Cambro-Ordovician allochthon; a smaller number of shows, notably in the Deer Lake Basin, and farther north at Conche, are found in, or adjacent to, much younger Carboniferous basins.

Source rocks, another of the key indicators for hydrocarbon prospectivity, are also well documented in this area (Sinclair, 1990; Fowler *et al*., 1995). Reports indicate as much as 10 percent TOC, and HI values as high as 759 (Fowler *et al*., 1995). In places on the Port au Port Peninsula, local fishermen have been known to burn shale flagstones as an accessory fuel for heating their stages and twine-lofts. So too, and farther inland, lacustrine oil shales are found in the Carboniferous strata of the Deer Lake Basin (Hyde *et al*., 1988; Hamblin *et al.*, 1997).

The identity of reservoir and cap rocks remain elusive targets. In the early days, exploration was purely wildcat drilling over and adjacent to hydrocarbon seeps (Fleming, 1970). Little was known of the geology and less about problems of engineering holes through folded and broken shale. The Parsons Pond area, in particular, is peppered with shallow and failed holes (some dating back to the 1860s), with some still containing trapped, broken, and corroded drill stems.

Before the latest round of exploration began there was a lengthy period of significant geological and geophysical research in western Newfoundland. Plate tectonic models of the evolution of western Newfoundland were developed along with a more complete understanding of the histories of the Taconic, Acadian and Alleghanian orogenies (Williams, 1975, 1993, 1995; Knight, 1983; James and Stevens, 1986; Cawood *et al*., 1988). Over the years, and amongst a large body of researchers and exploration geologists, a consensus began to emerge to indicate that dolomitized shallow-marine

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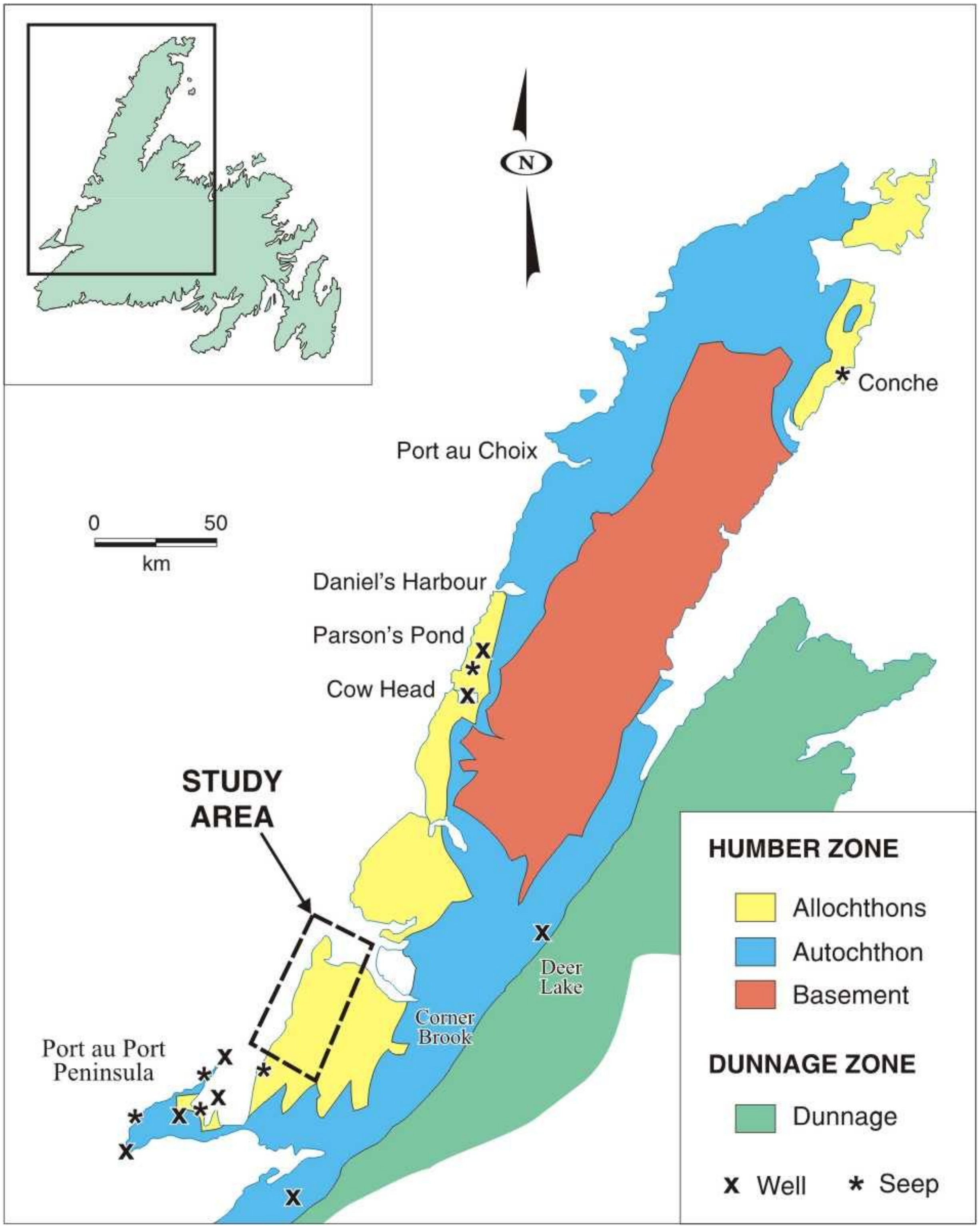

Figure 1. *Regional map of western Newfoundland showing tectonic terranes and localities where oil seeps and pyrobitumen are often reported.*

platform carbonates, buried beneath the allochthon, could form significant petroliferous reservoirs. Proper structural positioning of platform carbonate reservoirs adjacent to allochthonous shale source rock remained an issue, but with new seismic imaging, identifiable targets could now be explored (Stockmal *et al*., 1998). Furthermore, with seismic imagery, secondary targets might be located in allochthonous strata of the fold-and-thrust belts that lie upon the deformed carbonate platform.

In 1995, a new round of exploratory drilling on, and around, the Port au Port Peninsula was led by Hunt Oil, Pan Canadian Petroleum, Mobil Oil, and Talisman. The holes drilled tested large, seismically imaged structures formed in deeply buried carbonate platform rocks. Only one well, Port au Port #1, at Garden Hill, was identified as a significant discovery (Cooper *et al*., 2001). That said, commercial development has been frustrated by a realization that the reservoir is faulted and the pay zones are apparently isolated from one another.

In a very real sense, and for much of western Newfoundland, our limited understanding of the details of structure, stratigraphy, porosity and permeability continues to limit exploration success. If successes are to be achieved, surface mapping must, as much as anything else, continue to resolve the reservoir-scale details of the regional structure and stratigraphy.

About 5 years ago, the Geological Survey of Canada and the Newfoundland and Labrador Geological Survey entered into agreements under the NATMAP and TGI-2 programmes. As a part of these agreements, the sponsoring agencies are supporting a programme of detailed mapping and laboratory research at Memorial University of Newfoundland. One of the stated goals of this work is to provide geological data in support of hydrocarbon resource exploration and assessment.

Within its contribution to these national programmes, the research at Memorial University of Newfoundland has focussed upon the sedimentary strata of the Humber Arm Allochthon, and in particular the carbonate and clastic rocks lying on the flanks of the Blow Me Down and Lewis Hills massifs (Plate 1). As mapping of this region progresses, new data are addressing rift-margin stratigraphy, tectonostratigraphy, biostratigraphy, and thermal maturation. This report will touch upon the geology and structural assembly of a small part of the area where petroliferous strata apparently outline an exhumed and breached hydrocarbon reservoir.

REGIONAL GEOLOGY

Regional mapping of strata north of the community of Fox Island River shows a complex pattern of largely west-verging F_1 thrusts. The highest thrusts in the succession form the Blow Me Down and Lewis Hills massifs that tower over a narrow coastal plain of low, rounded hills and valleys (Plate 1). The Blow Me Down massif lies on the southern shore of the Bay of Islands (a large fjord). Nearby, the Lewis Hills Massif is situated about 15 km, south of the Bay of Islands, and 3 km south of the southern limit of the Blow Me Down massif.

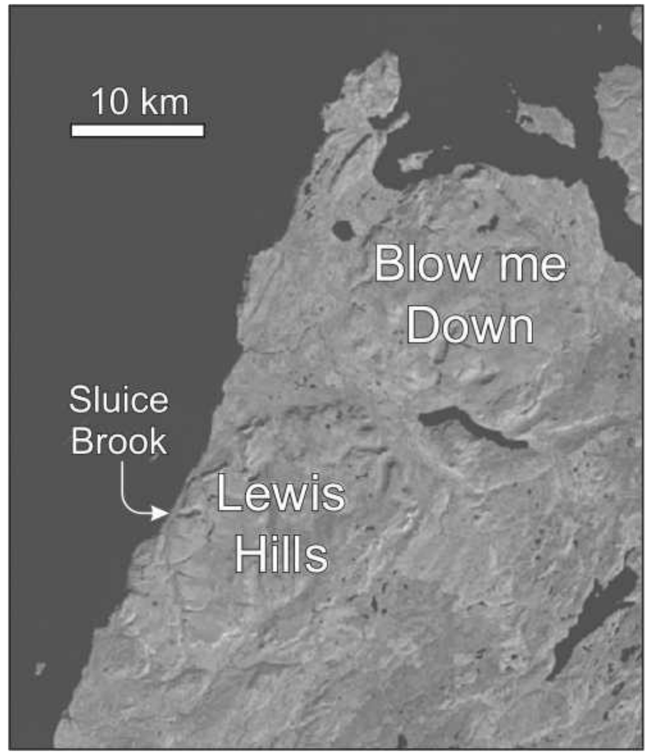

Plate 1. *Satellite image (from Geogratis, a Government of Canada website) showing the Blow Me Down and Lewis Hills massifs.*

The Lewis Hills Massif is a large, igneous body torn from its roots farther east and thrust upon older sedimentary and igneous rock. The massif is formed from trondhjemite, gabbro and basalt of the Little Port Complex, mafic gneiss and amphibolite of the Mount Barren Complex, and serpentinized harzburgite and dunite (mantle rock) of the Bay of Islands Complex (Williams and Cawood, 1989). Uranium–lead zircon ages reported in Jenner *et al*. (1991) and Kurth *et al*. (1998) show the Little Port trondhjemite to have crystallized in the middle Middle Cambrian (about 505 Ma); in contrast, the crystallization ages for gabbros from the nearby Blow Me Down massif and the eastern Lewis Hills are middle Tremadoc (about 484 Ma). There are no dates for the metamorphic rocks of the Mount Barren Complex.

The oldest sedimentary strata, belonging to the Blow Me Down Brook Formation, lie in the footwall of the Lewis

Hills and Blow Me Down massifs. Coastal exposures are predominantly, but not exclusively thick-bedded, fine- to coarse-grained and pebbly feldspathic and arkosic sandstones. Thinner bedded intervals in thrust panels may also contain red, grey, and black shale and siltstone holding simple, and low diversity, trace-fossil assemblages that commonly include *Oldhamia antiqua* Forbes, 1848 (Plate 2), a diagnostic Early Cambrian marker (Lindholm and Casey, 1990). Rich and diverse acritarch assemblages containing abundant *Skiagia* sp. are recorded from Blow Me Down Brook strata on the shore of the Bay of Islands (Palmer *et al*., 2001) and elsewhere in the area (E. Burden, unpublished data, 2005). In comparisons made with acritarch data presented in Moczydlowska (1998), the Blow Me Down Brook strata that carry abundant and diverse *Skiagia* sp. may be Tommotian. Tucker and McKerrow (1995) believe the top of the Tommotian lies at about 530 Ma, with the base at about 534 Ma. In contrast, Okulitch (1999) believes the Tommotian is somewhat younger - i.e., between 530 and 524 Ma.

Plate 2. Oldhamia antiqua Forbes, *from outcrop at the mouth of Sluice Brook.*

The lowest and youngest sedimentary strata within this F_1 thrust complex are thought to belong to the Northern Head Group. Rocks are normally seen as black and dark grey shales and siltstones and minor red and green shale, interlayered in varying proportions with pale grey, thin- to medium-bedded oolitic grainstone, limestone conglomerate and breccia. Dolomite and pyrite are sometimes seen as accessory minerals in these rocks. Sedimentary structures commonly show parts of the Bouma turbidite succession; other beds are extensively bioturbated. Successions of limestone beds can appear as repetitious ribbon-like intervals in the dark shales; in other localities, the dark shales contain few or no carbonate interbeds, and are mostly indistinguishable from shale-dominated Blow Me Down Brook strata.

Determining age and stratigraphic relationships for Northern Head Group strata in this region is confounded by very complex structure in largely incompetent rock. Shale-dominated panels occur as sheared and broken formation; ribbon carbonate beds can show multiple episodes of folding (Calon *et al.,* 2002). At this time, fossil analyses simply provide indications for age without much context. Collected fossil data reported in Kindle and Whittington (1965), Boyce *et al.* (1992), and Burden *et al.* (2001) indicate the carbonate and shale beds on the coast are Late Cambrian and Tremadoc.

GEOLOGY OF A BREACHED RESERVOIR

Often, over the course of this mapping programme, beds of blackened and petroliferous smelling strata were discovered (Plate 3). One particularly extensive belt of these oily sandstones occurs in a cliff section a few hundred metres north of Sluice Brook (Figure 2), which may be a breached hydrocarbon reservoir, in Blow Me Down Brook sandstone.

The exhumed part of this reservoir extends for more than 500 m along the coast and where the cliffs show a crudely antiformal shape (D_2) in a refolded F_1 thrust. Given that the coastal section provides the only data available, this two-dimensional profile leaves little opportunity for determining the true size and architecture of this feature. At this point, one can only speculate upon the subsurface orientation and dimensions, and the position of the former oil–water contact.

The core of this D_2 antiform is tightly folded and faulted Northern Head Group strata. The limestone and shale beds form a small east plunging anticline, in the hanging

Plate 3. *Outcrop of blackened and petroliferous smelling sandstone from the south limb of the D_2 antiform north of Sluice Brook.*

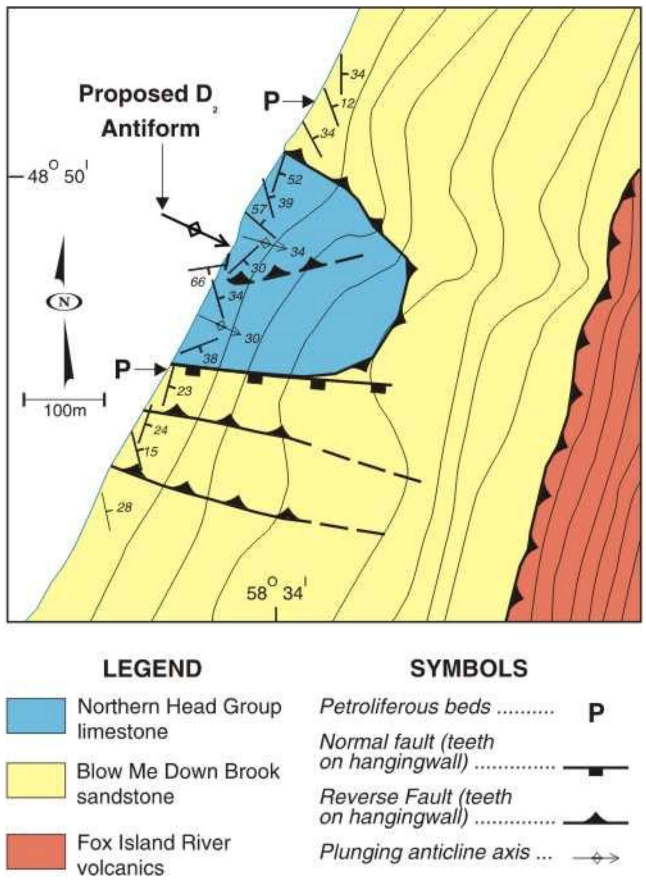

Figure 2. *Map of the local geology and structures of the breached reservoir.*

wall of a south verging F_2 forelimb thrust (Plate 4). A small, blind back thrust on the synclinal bend of the northern limb of the hanging wall anticline ends in overlying shaly strata. Similarly, a small wedge thrust lies adjacent to the southern limb of the hanging wall anticline; this also ends in the overlying shaly strata.

The footwall strata lying beneath the F_2 forelimb thrust are close to sea level and are mostly covered with beach boulders. Steeply dipping limestone beds lie directly below the subplanar F_2 fault ramp. A short distance south, and beyond what is now the steeply dipping rise of the F_2 thrust, the limestone beds apparently form the north limb and crest of a small, open folded, east plunging anticline. In overall composition and stratigraphy, the exposed limestone beds of the footwall appear similar to the lowest limestone beds in the anticline in the hanging wall. This suggests a relatively small amount of displacement on the F_2 forelimb thrust. So too, the length of this F_2 fault is unknown; in this reconstruction, it simply ends as a blind thrust in an accommodation zone in thickened and deformed strata on the crest of the larger D_2 antiformal structure.

Broken shaly, silty and sandy strata lie above the limestone beds of the Northern Head Group. These beds are thought to represent the fault zone of a west-verging F_1 thrust carrying Blow Me Down Brook strata over Northern Head Group. These beds also form an incompetent zone taking up the strain in the refolded and faulted Northern Head Group rocks. Never well exposed, these rocks are locally seen in the valley walls and near the mouth of a small stream on the northern limb of the D_2 antiform. They are not visible on the southern limb of the D_2 antiform; a late stage normal fault (F_3) has dropped the F_1 fault zone below sea level.

The hanging wall panel lying above the F_1 thrust plane is a blackened, oil-stained and slightly more quartzose facies of the Blow Me Down Brook sandstone. Strata contained in this interval are composed of mixed sandstone and shale beds (Figure 3). Sandstones occur as laminated and rippled, fine- to medium-grained beds 25 to 40 cm thick, and massive and laminated, petroliferous coarse-grained sandstone beds measuring 0.5 to 2 m thick. Black shale beds, measuring 0.1 to 2 m thick are interbedded with these quartzose sandstones. The strata contained in this petroliferous interval are more competent beds forming a distinctive horizon on the north and south limbs of the D_2 antiform. In the north, the beds verge to the south, but are absent on the crest of the D_2 antiform. In the south, the beds verge north, but are cut off from the crest of the D_2 antiform by a late stage normal fault (F_3).

DISCUSSION

In structurally complex fold and thrust belts, Mitra (2002) describes two major classes of deformation: 1) propagating thrusts faults that control the geometry and kinematics of major folds; and 2) accommodation faults that distribute strain within a structure. Accommodation faults are secondary features that impact directly upon the architecture of a structure. In particular, these faults result in, 1) compartmentalization of trap rocks, and 2) impact upon sealing capacity and recovery of fluids. Many of the features seen along this section of coastline can be attributed to fold accommodation faulting and the development of a wedge thrust into a D_2 antiform hinge (Figure 4). A late-stage normal fault on the south side of the D_2 antiform dropped petroliferous Blow Me Down Brook sandstones to their present position.

The proposed succession of tectonic events involves three stages of deformation. Following sedimentation in the

Plate 4. *Detail of outcrop showing small accommodation faults in Northern Head Group limestone and shale beds that form a small east plunging anticline, in the hangingwall of a south verging F_2 forelimb thrust.*

Cambrian and Early Ordovician, an episode of tectonism (D_1) generated west-verging thrusts (F_1) that inverted strata, placing older, Early Cambrian clastic rock of the Blow Me Down Brook Formation upon younger, deep-water carbonates and shales of the Northern Head Group. A second episode of deformation (D_2) has folded sandstone and carbonate into an F_2 antiform. The space needed for tight folding of the core of the antiform resulted in a south verging accommodation thrust, that is a wedge thrust (F_2) into incompetent shale beds in the carbonate and extending into the F_1 thrust zone. The overlying and competent Blow Me Down Brook sandstone assumed an antiformal shape. So too, and at this time, it is assumed that the sandstones of the Blow Me Down Brook sandstone and shale succession became charged with hydrocarbons. Continued D_2 deformation may have ruptured the Blow Me Down Brook sandstone along fractures on the crest of the D_2 antiform, breaching the reservoir and allowing fluids to escape. Alternatively, a third episode of deformation D_3 occurred long after the D_2 events and resulted in a F_3 normal fault; this dropped a large part of the south limb of the antiform to its present position, and leaving a conduit for fluids to escape.

Timing for all of this deformation is mostly unknown. The first west-verging structures may be a part of the Taconic Orogeny. South-verging structures are not normally reported or discussed. An Acadian age for deformation is, in one sense, likely; F_2 thrusts and folds are imprinted upon the D_1 structures. However, Acadian structures are considered to carry west vergences. Alleghenian deformation is considered to be a product of northeast-striking strike-slip faults. Strain on these fault systems should be seen as normal and reverse faults, and folds that are oriented at a high angle to the main strike-slip system; i.e., with fault trends and fold axes oriented in a more east–west direction.

IMPLICATIONS FOR HYDROCARBON EXPLORATION

In their summary report on hydrocarbon exploration of the Port au Port Peninsula, Cooper *et al.* (2001) indicated that Cambrian sandstones of the Hawke Bay Formation could be a worthwhile secondary target. The discovery and identification of petroliferous Blow Me Down Brook sandstones confirms the merit of Cambrian clastic strata as a target and extends Cambrian clastic plays from the shallow platform and into deeper water submarine fan deposits of the allochthon. With thrust faulted and repeated sections of shaly allochthonous source beds lying adjacent to coarse-grained clastic reservoir rocks, it is not unreasonable to expect porous and permeable beds of Blow Me Down Brook sandstone to become charged with hydrocarbons. Secondary accommodation faulting, as visualized in this outcrop study, and perhaps tied to a later phase of Acadian or Alleghanian deformation, indicates that petroliferous structures may in fact be oriented across the prevailing west verging grain of the Taconic orogen.

On the cautionary side, a later phase of accommodation faulting may pose significant problems for exploration and development geologists attempting to determine reservoir architecture, trap integrity and sealing capacity. Leaky faults may allow fluids to escape; tight faults with significant offsets can turn a reservoir into a mosaic of small and uneconomic traps.

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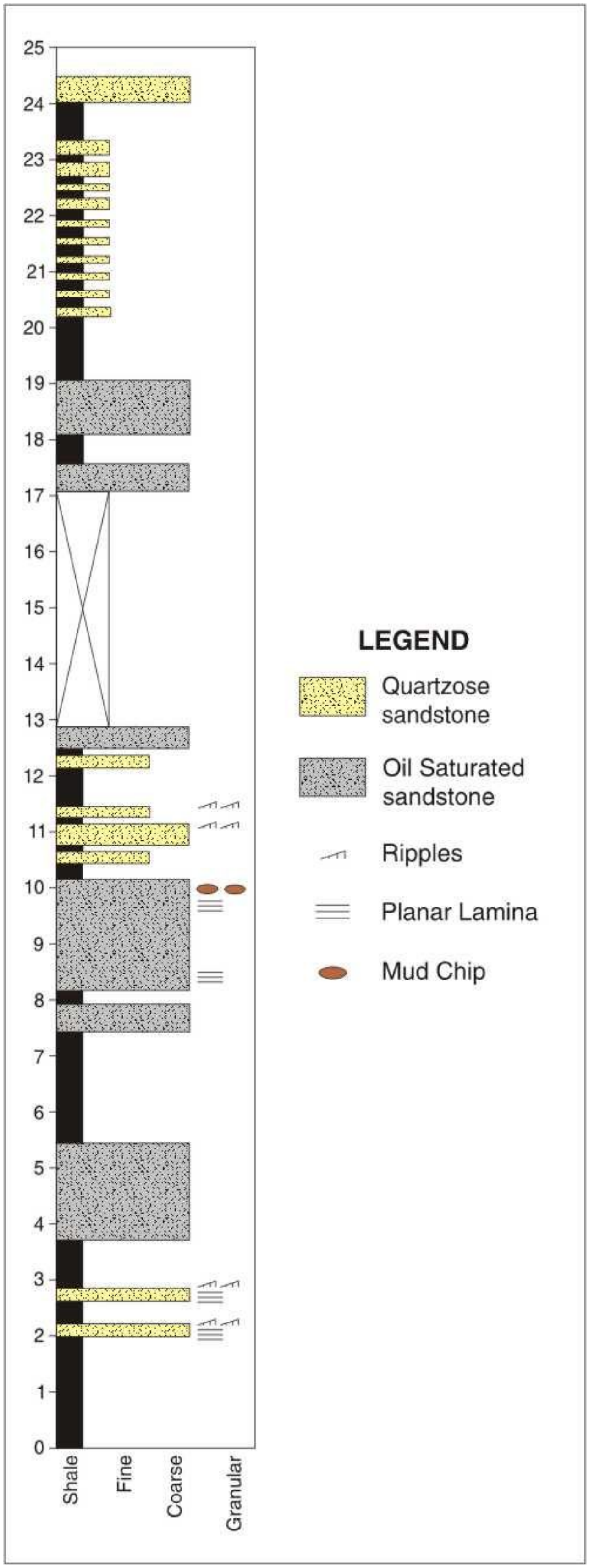

Figure 3. (opposite) *Stratigraphic section from sandstone beds of the Blow Me Down Brook Formation on the south limb of the antiform show mixed sandstone and shale beds containing discrete petroliferous horizons up to 2 m thick.*

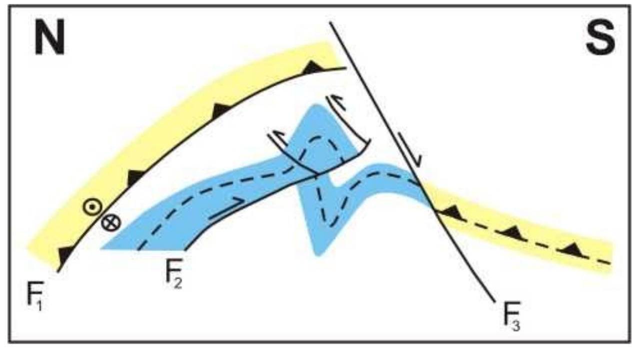

Figure 4. *Schematic cross-section showing the principal elements of the wedge thrust system and broken D_2 antiform; Northern Head Group - blue; Blow Me Down Brook Formation - yellow.*

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REFERENCES

Baird, D.M. and Snelgrove, A.K.
1953: Mines and Mineral Resources of Newfoundland. Geological Survey of Newfoundland, Information Circular No. 4.

Boyce, W.D., Botsford, J.W. and Ash, J.S.
1992: Preliminary trilobite biostratigraphy of the Cooks Brook Formation (Northern Head Group), Humber Arm Allochthon, Bay of Islands, western Newfoundland. *In* Current Research. Newfoundland Department of Mines and Energy, Geological Survey, Report 92-1, pages 55-68.

Burden, E., Calon, T., Normore, L. and Strowbridge, S.
2001: Stratigraphy and structure of sedimentary rocks in the Humber Arm Allochthon, southwestern Bay of Islands, Newfoundland. *In* Current Research. New-

foundland Department of Mines and Energy, Geological Survey, Report 01-1, pages 15-22.

Calon, T., Buchanan, C., Burden, E., Feltham, G. and Young, J.
2002: Stratigraphy and structure of sedimentary rocks in the Humber Arm Allochthon, southwestern Bay of Islands, Newfoundland. *In* Current Research. Newfoundland Department of Mines and Energy, Geological Survey, Report 02-1, pages 33-45.

Cawood, P.A., Barnes, C.R., Botsford, J.W., James, N.P., Knight, I., O'Brien, S.J., O'Neill, P.P., Parsons, M.G., Stenzel, S.R., Stevens, R.K., Williams, H. and Williams, S.H.
1988: A cross-section of the Iapetus Ocean and its continental margins: Field Excursion Guidebook. Vth International Symposium on the Ordovician System (ICS/IUGS IGCP Project 216), St. John's Newfoundland, 144 pages.

Cooper, M., Weissenberger, J., Knight, I., Hostad, D., Gillespie, D., Williams, H., Burden, E., Porter-Chaudhry, J., Rae, D. and Clark, E.
2001: Basin evolution in western Newfoundland: New insights from hydrocarbon exploration. American Association of Petroleum Geologists, Bulletin, Volume 85, pages 393-418.

Eaton, S.
2004: Looking for new found oil in Newfoundland: Structure, dolomites look good. American Association of Petroleum Geologists Explorer, Volume 25, Number 3, page 18.

Fleming, J.M.
1970: Petroleum exploration in Newfoundland and Labrador. Mineral Resources Division, Department of Mines, Agriculture and Resources, Province of Newfoundland and Labrador, Mineral Resources Report, No. 3, 118 pages.

Fowler, M.G., Hamblin, A.P., Hawkins, D., Stasiuk, L.D. and Knight, I.
1995: Petroleum geochemistry and hydrocarbon potential of Cambrian and Ordovician rocks of western Newfoundland. Bulletin of Canadian Petroleum Geology, Volume 43, pages 187-213.

Hamblin, A.P., Fowler, M.G., Utting, J., Langdon, G.S. and Hawkins, D.
1997: Stratigraphy, palynology and source rock potential of lacustrine deposits of the Lower Carboniferous (Viséan) Rocky Brook Formation, Deer Lake Subbasin, Newfoundland. Bulletin of Canadian Petroleum Geology, Volume 45, pages 25-53.

Henry, J.D.
1910: Oil fields of the empire. Bradbury, Agnew and Company, Ltd., London, pages 212-278.

Hyde, R.S., Miller, H.G., Hiscott, R.N. and Wright, J.A.
1988: Basin architecture and thermal maturation in the strike-slip Deer Lake Basin, Carboniferous of Newfoundland. Basin Research, Volume 1, pages 85-105.

James, N.P. and Stevens, R.K.
1986: Stratigraphy and correlation of the Cambro-Ordovician Cow Head Group, western Newfoundland. Geological Survey of Canada, Bulletin 366, 143 pages.

Jenner, G.A., Dunning, G.R., Malpas, J., Brown, M. and Brace, T.
1991: Bay of Islands and Little Port complexes, revisited: age, geochemical and isotopic evidence confirm suprasubduction-zone origin. Canadian Journal of Earth Sciences, Volume 28, pages 1635-1652.

Kindle, C.H. and Whittington, H.B.
1965: New Cambrian and Ordovician fossil localities in western Newfoundland. Geological Society of America, Bulletin, Volume 76, pages 683-688.

Knight, I
1983: Geology of the Carboniferous Bay St. George Subbasin, western Newfoundland. Newfoundland Department of Mines and Energy, Mineral Development Division, Memoir 1, 358 pages.

Kurth, M., Sassen, A., Suhr, G. and Mezger, K.
1998: Precise ages and isotopic constraints for the Lewis Hills (Bay of Islands Ophiolite): Preservation of an arc-spreading ridge intersection. Geology, Volume 26, pages 1127-1130.

Lindholm, R.M. and Casey, J.F.
1990: The distribution and possible biostratigraphic significance of the ichnogenus *Oldhamia* in the shales of the Blow Me Down Brook Formation, western Newfoundland. Canadian Journal of Earth Sciences, Volume 27, pages 1270-1287.

Mitra, S.
2002: Fold-accommodation faults. American Association of Petroleum Geologists, Bulletin, Volume 86, pages 671-693.

Moczydlowska, M.
1998: Cambrian acritarchs from Upper Silesia, Poland - biochronology and tectonic implications. Fossils and Strata, Volume 46, pages 1-121.

Okulitch, A.V.
1999: Geological Time Scale, 1999. Geological Survey of Canada, Open File 3040.

Palmer, S.E., Burden, E. and Waldron, J.W.F.
2001: Stratigraphy of the Curling Group (Cambrian), Humber Arm Allochthon, Bay of Islands. *In* Current Research. Newfoundland Department of Mines and Energy, Geological Survey, Report 2001-1, pages 105-112.

Sinclair, I.K.
1990: A review of the Upper Precambrian and lower Paleozoic geology of western Newfoundland and the hydrocarbon potential of the adjacent offshore area of the Gulf of St. Lawrence. Canada Newfoundland Offshore Petroleum Board, 57 pages.

Stockmal, G.S., Slingsby, A. and Waldron, J.W.F.
1998: Deformation styles at the Appalachian structural front, western Newfoundland: Implications of new industry seismic reflection data. Canadian Journal of Earth Sciences, Volume 35, pages 1288-1306.

Tucker, R.D. and McKerrow, W.S.
1995: Early Paleozoic chronology: A review in light of new U-Pb zircon ages from Newfoundland and Britain. Canadian Journal of Earth Sciences, Volume 32, pages 368-379.

Williams, H.
1975: Structural succession, nomenclature, and interpretation of transported rocks in western Newfoundland. Canadian Journal of Earth Sciences, Volume 12, pages 1874-1894.

1993: Acadian orogeny in Newfoundland. *In* The Acadian Orogeny: Recent Studies in New England, Maritime Canada, and the Autochthonous Foreland. *Edited by* D.C. Roy and J.W. Skehan. Geological Society of America, Special Paper 275, pages 123-133.

1995: Temporal and spatial subdivisions of the rocks of the Canadian Appalachian region. *In* Geology of the Appalachian-Caledonian Orogen in Canada and Greenland. *Edited by* H. Williams. Geological Survey of Canada, Geology of Canada, No. 6, pages 21-44.

Williams, H. and Cawood, P.A.
1989: Geology, Humber Arm Allochthon, Newfoundland. Geological Survey of Canada, Map 1678A.