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SYNDEPOSITIONAL TRANSPORT ON A DEEP-MARINE SLOPE AND SOFT-SEDIMENT REWORKING OF DETRITUS FROM AN EXHUMED IAPETAN ARC: EVIDENCE FROM THE UPPER NEW BAY FORMATION OF THE EXPLOITS GROUP

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ABSTRACT

The New Bay Formation (Exploits Subzone, Dunnage Zone) is a deep-marine sedimentary sequence, which accumulated during back-arc rifting at the Gondwanan margin of Iapetus during probably late Arenig times. The formation consists of fine-grained turbidites with interbedded debrites and thick olistostrome deposits, the products of syndepositional, submarine mass-flow processes. Detailed sedimentological analysis of the upper New Bay Formation in well-exposed coastal sections around the Bay of Exploits suggests a slope apron or lower turbidite fan-depositional setting. Exotic clast types within the mass-flow deposits include limestones, plutonic rocks (some foliated), mafic volcanic rocks, and pillow basalts of tholeiitic composition with rare-earth-element signatures typical of arc-related lavas. Clast types suggest derivation from a volcano-plutonic Iapetan arc complex.

TECTONIC INTRODUCTION

The earliest Caradoc and older rock units of the Exploits Subzone of the Newfoundland Dunnage Zone comprise relicts of Iapetan arc-root complexes and supracrustal arc sequences overlain by variably thick, sediment-dominated overstep successions (Colman-Sadd *et al.*, 1990, 1992b). Arc-related rocks are both older and younger than the Exploits Subzone's Tremadoc ophiolite fragments (Dunning *et al.*, 1991; Spray and Dunning, 1991), which are deemed to have originated in a suprasubduction zone setting near the Gondwanan margin of Iapetus (Jenner and Swinden, 1993; Williams *et al.*, 1992b). The volumetrically subordinate volcanic strata of the overstep successions contrast, geochemically, with the underlying mature and immature arc-volcanic rocks, and are interpreted to have formed in a variety of non-arc paleotectonic settings (Swinden *et al.*, 1990; Dec *et al.*, 1992).

The subzone's Early Ordovician history essentially reflects the varying extents to which regions containing mid-Arenig and older rocks were affected by Penobscot tectonism, a phenomenon ultimately associated with ocean–continent interaction on the orogen's southeast margin (Williams and Piasecki, 1990; Dec and Colman-Sadd, 1990; Tucker *et al.*, *in press*). The Early to Mid Ordovician evolution of the Exploits Subzone appears, in turn, to have been fundamentally controlled by lateral spatial variations in the marine depositional environment of late Arenig and younger rocks (O'Brien, 1991; Currie, 1993) and by the generation and tectonic influence of coeval magmatic and metamorphic rocks (Colman-Sadd *et al.*, 1992a).

REGIONAL GEOLOGICAL SETTING

The stratigraphical and geochemical record of an ensimatic arc–arc rift–back-arc transition within the Wild Bight Group of the Exploits Subzone (Swinden *et al.*, 1990) is also preserved in the tectonically adjacent Exploits Group (B.H. O'Brien, unpublished data; Dec *et al.*, 1993b). The New Bay Formation of the Exploits Group (Helwig, 1967) accumulated in part during the arc-rift phase, which was contemporaneous with mafic sill emplacement and possibly with uplift and intrusion of the oldest exposed formations in the group. In the context of the regional geology, the upper New Bay Formation is a precursor unit, reflecting intrabasinal tectonic conditions immediately prior to the development of the back arc and its subsequent drowning and burial by starved pelagic shale (O'Brien, 1991).

Although the upper New Bay Formation is fault-bounded or tectonically removed in certain localities, this highly distinctive subdivision is developed around the periphery of most of the outcrop area of the Exploits Group (O'Brien, 1990, 1992, 1993b). It is well displayed adjacent to the Tremadoc–Llandeilo olistostromal Dunnage Melange (Hibbard, 1976), where Exploits Group back-arc volcanosedimentary

[1] Newfoundland Mapping Section

formations and overlying Caradoc black shale have been completely displaced or partially excised by thrust faulting (O'Brien, 1993a). This same situation exists in other parts of the region where the upper New Bay Formation of the Exploits Group is tectonically juxtaposed with several other marine and terrestrial rock groups within the Exploits Subzone (Figure 1).

LOCATION OF STUDY AREAS

Detailed sedimentological examinations of the upper New Bay Formation have been made along coastal sections at Phillips Head, Michael's Harbour and Campbellton in the Bay of Exploits (Figure 1). The Michael's Harbour and Phillips Head exposures offer almost continuous sections through sequences affected by only weak tectonic deformation, although inland exposure is poor. The Campbellton exposures are in a zone of ductile deformation, which has produced strong L-tectonites and, therefore, is of little use to a stratigraphical and sedimentological study of this nature. Nevertheless, there is no doubt that, north of Campbellton, at least some of the Exploits Group strata that structurally underlie dated late Caradoc rocks (and are in direct fault contact with the Dunnage Melange) belong to the upper New Bay Formation.

BIOSTRATIGRAPHICAL AGE OF THE UPPER NEW BAY FORMATION

Extensive searches in the fine-grained turbidites of the formation along the coastal sections at Michael's Harbour have yielded only very few, badly preserved graptolites. The only identifiable specimen of stratigraphical significance is a possible *Sigmagraptus* (S.H. Williams, personal communication 1993), indicating a pre-Llandeilo age. However, graptolites obtained from the overlying Strong Island Chert are of latest Arenig or earliest Llanvirn age (Williams *et al.*, 1992a). A number of samples of bedded siltstones and silty mudstones from Michael's Harbour were acid digested to test for the presence of acritarchs, but the samples proved to be unfossiliferous. An early to mid Arenig conodont assemblage (Hibbard *et al.*, 1977) obtained from a limestone clast from the New Bay Formation gives an oldest age limit for the deposition of the upper part of the formation. The biostratigraphical evidence collectively indicates a post-early Arenig and pre-early Llanvirn age for the formation.

SEDIMENTOLOGY OF THE UPPER NEW BAY FORMATION

LITHOFACIES

Michael's Harbour

A portion of the upper New Bay Formation is well exposed on the western side of the small unnamed island, connected to the settlement of Michael's Harbour (Figure 1) by a narrow isthmus exposed at low tides. Here, the formation faces stratigraphically southeast, becoming younger away from the Dunnage Melange and toward the fault-bounded terrestrial formations of the Silurian Botwood Group (Figure 1). Near Michael's Harbour, the upper New Bay Formation consists of turbiditic mudstones and siltstones, with at least four interbedded debrite units. Gaps in exposure make it difficult to assess the relative proportion of these two facies within the sequence, but along the western shores of the island, the ratio is estimated to be approximately 1:1.

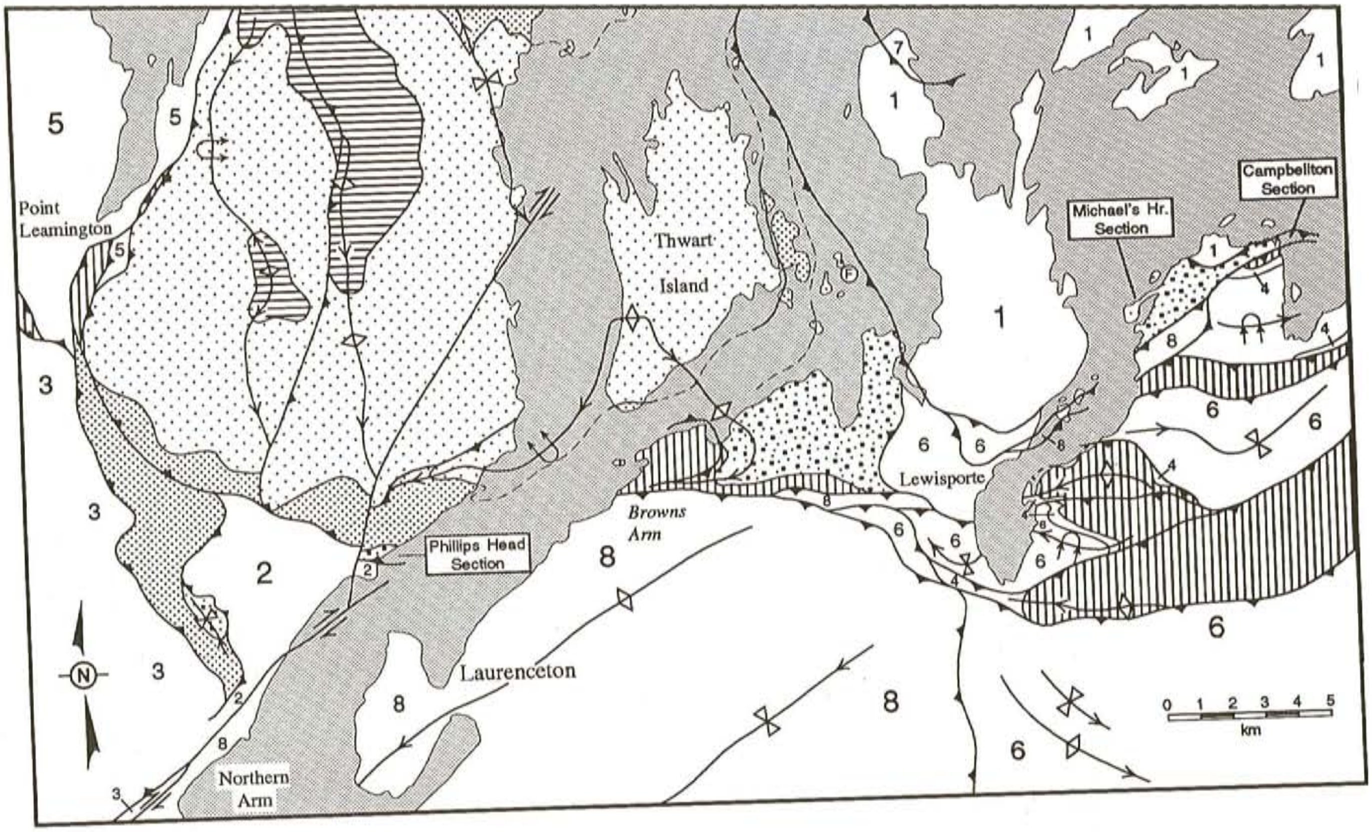
The turbidites are mainly thin- to medium-bedded, dark-grey, silty mudstones, siltstones and argillaceous fine-grained sandstones, with rare, quartz granule-rich coarse-grained sandstones. Normal grading, weakly erosive bases, and Bouma A-B sequences in the thicker, coarser beds prove the correct structural way-up of the sequence. Hemipelagite laminae are rare, but have yielded poorly preserved, indeterminate graptolite fragments.

Two debrite beds, one approximately 6 m and the other 8 m thick, are well exposed on the southwest shores of the island, with top and bottom contacts visible (Plates 1, 2 and 3). The debrites consist of chaotic, completely unsorted mixtures of intraformational sedimentary clasts and exotic clasts of unfossiliferous limestone, felsic plutonic rocks and mafic–felsic volcanic and hypabyssal rocks, set in a mainly dark-grey, quartz-rich argillaceous matrix. No internal stratification of the debrites is recognizable, their bases are regular and non-erosive, and there appears to be no topographical relief on the tops of the units. Matrix- and clast-supported zones merge imperceptibly into each other, emphasising the chaotic nature of the deposits (Plates 1 and 2). Exotic clasts are very well rounded and mostly less than 15 cm across, but rarely reach up to 30 cm in size. In marked contrast, the sedimentary lithoclasts are highly irregular in shape and size, one such clast being 6 m long and 0.80 m thick. Although most of the sedimentary lithoclasts retain an internal primary lamination, they also exhibit soft-sediment deformation features, and were clearly in a highly plastic state when incorporated into the debris flow (Plate 3).

At least two more debrite units are present on the northwestern shores of the island, again interbedded with fine-grained turbidites. The upper and lower contacts of these units are less distinct than those described above, and it is therefore difficult to determine their stratigraphical thickness. The lower 3 m of one debrite is inversely graded. Parts of these beds are strongly matrix-supported, with exotic clasts suspended in a volumetrically dominant argillaceous matrix. The chaotic nature, clast content, variation in rounding and size of exotic and sedimentary clasts, and plasticity of sedimentary clasts in these deposits is identical to that described above.

Phillips Head

Mass-flow deposits of the upper New Bay Formation are also present in coastal exposures around Phillips Head (Figure 1), in primary contact with turbidite mudstones, siltstones and fine-grained sandstones. Immediately northeast of the settlement, these rocks are stratigraphically underlain by the



Llandovery to Ludlow(?)

8 — *Botwood Group (Wigwam and Lawrenceton Formations*

Ashgill and Llandovery

7 — *Upper Black Island argillite*

Ashgill

6 — *Campbellton greywacke and Lewisporte conglomerate*

Caradoc and Ashgill

5 — *Point Leamington Formation*

Caradoc

4 — *Lawrence Harbour Formation*

3 — *Shoal Arm Formation*

Arenig to Llandeilo(?)

Exploits Group

Back-arc formations

Upper New Bay Formation

Middle New Bay Formation

Lower New Bay Formation

Arc-related formations

Arenig(?)

2 — *Phillips Head Igneous Complex*

Tremadoc to Llandeilo

1 — *Dunnage Melange*

SYMBOLS

Stratigraphical boundary (approximate, assumed)..........................

Fossil locality (conodonts)......................... Ⓕ

Reverse fault (barbs in direction of dip)...

Strike-slip fault (dextral).............................

Anticline (upright, overturned)..................

Syncline (upright, overturned)....................

Fold axial trace (plunge indicated)...........

Figure 1. *Regional geological map of the southeastern margin of the Early–Middle Ordovician Exploits Group depicting its external relationships, and the disposition of its younger constituent formations. The internal subdivisions of the New Bay Formation are indicated; also located are the areas in which the upper New Bay Formation was examined for this paper.*

Plate 1. *Upper New Bay Formation, Michael's Harbour: unsorted debrite consisting of subrounded exotic clasts of limestone, plutonic rocks and mafic volcanic rocks in sand- to mud-grade matrix. Note the intraformational mudstone clast wrapping around an exotic to the right of the pencil.*

Plate 2. *Upper New Bay Formation, Michael's Harbour: unsorted debrite with a large, irregular sedimentary lithoclast in a pebbly matrix containing abundant exotic clasts.*

shaley medial division of the formation (Figure 2). With the exception of some beds immediately adjacent to the subdivision's thrust-faulted contact with arc-related rocks of the Phillips Head Igneous Complex, upper New Bay Formation strata generally face southward and are commonly inverted. An interpretation of the stratigraphical and structural

Plate 3. *Upper New Bay Formation, Michael's Harbour: folded mudstone lithoclast demonstrating plasticity of intraformational material during debrite emplacement.*

disposition of Exploits Group magmatic arc, arc-derived and non-arc sequences, at and northeast of Phillips Head, is schematically depicted in Figure 2.

At Phillips Head, upper New Bay Formation debrites again consist of a chaotic mixture of intraformational sedimentary and exotic clasts in an argillaceous/arenaceous matrix (Plates 4 and 5). Clast- and matrix-supported zones are present. Sedimentary clasts have irregular shapes and show features of plastic deformation, whereas the exotic magmatic and limestone clasts are smaller and well rounded. One exotic clast (Plate 6) is a 'raft' up to 12 m across (see below for description of rock type).

In contrast to the Michael's Harbour sequence, it is not possible to identify individual debrite units or turbidite interbeds at Phillips Head. These rocks are therefore more likely to be the products of a single, catastrophic mass-flow event, an olistostrome, with a thickness of up to 185 m.

CLAST TYPES

Clast types at Michael's Harbour and Phillips Head are similar. The above mentioned 12 m raft from Phillips Head consists of feldspar-phyric, vesicular pillow basalt with associated pillow breccias (Plate 6), and although no clasts even approach this size at Michael's Harbour, single pillow clasts of similar appearance are present. Other exotic clast types are mainly strained vein quartz, but also include grey micritic limestone, granitoids and rarer diorites (some foliated), felsic and mafic porphyries, and probable mixed volcanic clasts.

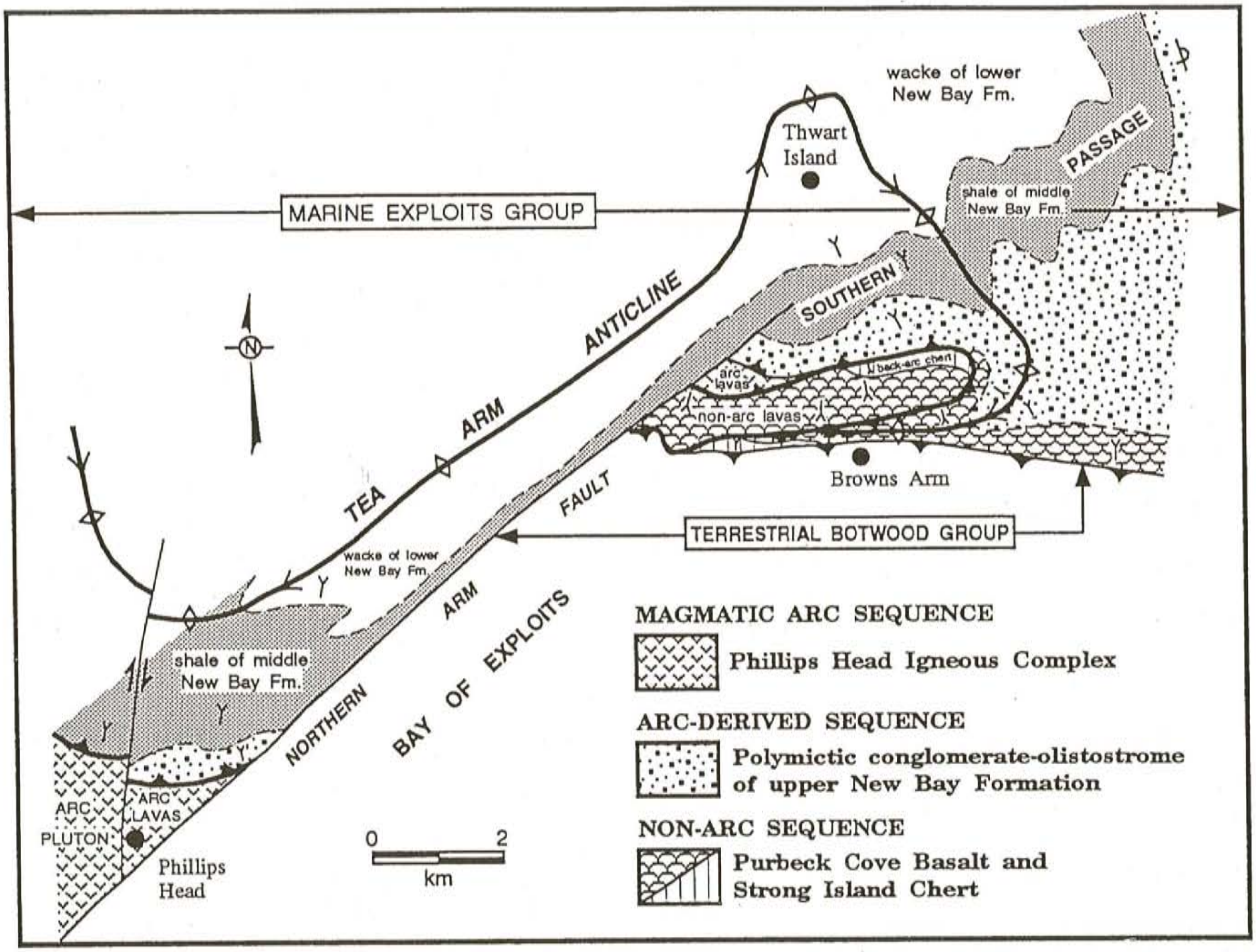


Figure 2. *Interpretative map of onshore and offshore areas of the Phillips Head–Thwart Island–Browns Arm region illustrating the lithostratigraphical distribution and structural juxtaposition of proposed magmatic arc, arc-derived and non-arc sequences near the southeastern termination of the regional Tea Arm Anticline. Note the stratigraphical and structural position of the upper New Bay Formation section examined at Phillips Head.*

The sedimentary clasts are mainly laminated dark-grey muddy fine-grained sandstones, muddy siltstones and silty mudstones. They bear a strong resemblance to the fine-grained turbidites, which are present in the approximately 350 km^2 outcrop area of the lower and middle New Bay Formation, and can justifiably be called intraformational. It is clear from the plastic deformation of the more coherent lithoclasts, and from the intimate mixing of mud-, silt- and sand-grade particles in the matrix, that the sediment incorporated into these debrites was mainly unconsolidated.

CLAST PROVENANCE

The exotic clast population of the upper New Bay Formation includes sedimentary, volcanic, plutonic and metamorphic rocks. Some of the exotic, well-rounded, polymict cobbles and boulders observed in the formation resemble those from the better known Ashgill and Llandovery conglomeratic turbidites of the Exploits Subzone (Colman-Sadd *et al.*, 1992b; Dec *et al.*, 1993a). The latter have been historically interpreted as filling tectonically active basins located adjacent to the Notre Dame Subzone (e.g., Nelson, 1981; Arnott *et al.*, 1985) and as recording the earliest known tectonic uplift of the Exploits Subzone's Early Ordovician rocks, oceanward of the zone of Penobscot obduction.

The exotic limestone detritus within the upper New Bay Formation is in sharp contrast with the coral-rich, shallow-water, Ashgill–Llandovery limestone clasts resedimented in the above-mentioned turbidite basins. Although the upper New Bay carbonate detritus is apparently devoid of a shelly macrofauna, in at least one locality, a grey micritic limestone clast (intimately associated with mafic tuff) has been reported to contain conodonts. The probable early to mid Arenig conodont assemblage (Hibbard *et al.*, 1977) has been interpreted as dating parts of both the New Bay Formation and the Dunnage Melange. Regardless, such clasts indicate that the catchment area ultimately feeding the upper New Bay

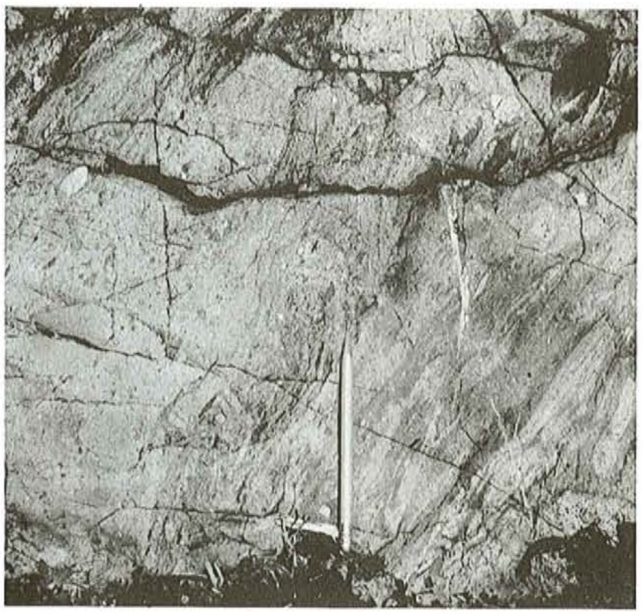


Plate 4. *Upper New Bay Formation, Phillips Head. Wave-polished surface showing soft-sediment deformation during emplacement of matrix-supported debrite. Streaked out lozenges of mudstone are dark grey in a matrix of pale-grey siltstone and sandstone. Rounded exotic clasts are visible in the left and top of the photograph.*

Plate 5. *Upper New Bay Formation, Phillips Head. Debrite with rounded exotic clasts of mafic volcanic origin enclosed in silty mudstone matrix.*

debris flows contained mafic volcanic rocks that had once lain above carbonate compensation depths. In the authors' opinion, the conodont-bearing limestone clasts provide an older age limit for deposition of the upper New Bay Formation.

Plate 6. *Upper New Bay Formation, Phillips Head. Raft of basaltic pillow lavas and associated breccias (see text for compositional details) within olistostrome. The hammer adze rests against a small pillow, and others are visible in the lower and right halves of the photograph. The flat face to the left of the hammer consists of pillow breccias.*

Plutonic detritus, which is variably deformed and metamorphosed, is a very common extrabasinal component of upper New Bay polymictic conglomerate. The chief clasts are, in order of decreasing grain size, granodiorite and gabbro (displaying primary igneous or foliated textures), less common well-banded orthogneiss, and strained lit-par-lit quartz veinlets. In contrast to Helwig's (1967) statements, such detritus indicates that New Bay source areas were composed of uplifted and eroded, deep-level intrusive rocks, as well as the extrusive and deep-water carbonate rocks mentioned above.

This foliated plutonic material could have originated in sialic crust and been weathered from a regionally deformed and metamorphosed tract of rocks older than the Exploits Group, although units of this type and age have not been recognized in the Notre Dame Bay sector of the Exploits Subzone. Alternatively, the exotic metaplutonic detritus may have had its source in an ensimatic arc-root complex, which was partly coeval with the supracrustal limestone-bearing volcanic sequences. Arc-related igneous complexes outcropping near the Exploits Group are known to contain ophiolitic flaser gabbro, variably sheared tonalites and diorites, and swarms of mafic–felsic porphyritic dykes.

The most ubiquitous and largest detrital clasts in the upper New Bay Formation are mafic volcanic rocks, however, uncertainty exists as to whether this detritus has an intrabasinal or extrabasinal provenance. In places, thick conglomerates made up entirely of basalt fragments are interstratified with thin-bedded turbidite mudstone, siltstone and sandstone sequences. An important feature of the monolithic deposits is the occurrence of highly spherical, iron-oxidized (reddened), vesicular basalt boulders between 25 and 60 cm in diameter, set in a greenish-grey epiclastic matrix. The grain size, roundness and alteration of the boulders, together with the dominance of one textural variety of basalt, suggest derivation of already oxidized material from one site, perhaps the storm beach of a volcanic island.

The mega-raft of bedded pillow lava and pillow breccia that was transported in the Phillips Head olistostrome yields information pertinent to the provenance of mafic volcanic detritus in the upper New Bay Formation. A geochemical analysis of a pillow from within the raft is reported in Table 1. This data indicates an overall tholeiitic composition for the basalt; the pattern of the extended REE-plot for the same specimen (Figure 3) demonstrates a signature typical of the arc-related pillow lavas in the Exploits and Wild Bight groups (Swinden *et al.*, 1990; Dec *et al.*, 1992). Although the petrochemical data indicate that at least some basalt clasts had their origin in a volcanic island arc, such mafic volcanic detritus need not have necessarily come from the sub-New Bay Formation volcanic strata of the Exploits Group (e.g., Figure 3; O'Brien, 1991).

DEPOSITIONAL PROCESSES

Michael's Harbour

Chaotic sedimentary fabrics, the absence of sorting, and the lack of significant internal stratification are features typical of debrites (e.g., Pickering *et al.*, 1989, p. 29). There is no doubt that the rocks described above are the products of submarine debris flows. However, a depositional model must also be able to explain the presence of abundant, very well-rounded, exotic clasts within the debrites. Fragments of lithified clastic carbonate occur as detrital constituents of conglomerates that comprise blocks within debris flows, and indicate that at least some resedimented cobble- and boulder-detritus is polycyclic. It is probable that many of the exotic clasts were introduced into the deep-marine environment as turbidity current bedload through submarine channels, because their large size clearly discounts the possibility of their introduction in suspension. The chaotic mixing of exotic and intraformational material in the debrites can be explained by a number of models.

The collapse and redeposition by debris flow of an unconsolidated submarine sediment pile, containing conglomerates (supplied with exotic clast material by turbidite feeder channels), laminated turbidite mudstones, siltstones and fine-grained sandstones, could produce the debrites described above. Earthquake shocks could provide the trigger for mobilization of debris flows, and the presence of multiple debrite units at Michael's Harbour certainly suggests contemporaneous tectonic instability. It is even possible that syndepositional faults played a role in the exhumation or docking and subsequent erosion of metamorphosed plutonic rocks, such as those now seen as debrite clasts or in present outcrop near the Exploits Group.

Table 1: Geochemical analyses of pillow basalts; one from a detrital raft in the upper New Bay Formation (BHOB-28-92), and the other from the tectonically adjacent Phillips Head Igneous Complex (BHOB-27-92). Major elements in weight percent; trace elements in ppm

	BHOB-28-92 (2540112)	BHOB-27-92 (2540111)
SiO_2	48.01	46.64
Al_2O_3	16.25	15.87
Fe_2O_3	1.19	0.88
FeO	8.49	8.81
MgO	7.11	9.04
CaO	9.03	8.29
Na_2O	4.04	3.43
K_2O	0.03	0.18
TiO_2	0.987	0.999
MnO	0.161	0.182
P_2O_5	0.078	0.077
LOI	3.85	4.51
TOTAL	100.17	99.89
Sc	32.2	36.0
Cr	170	340
Co	38	49
Ni	81	180
Zn	25	25
As	8.1	18.0
Se	1	1
Br	1.0	0.6
Rb	2.0	2.0
Y	21.446	22.407
Zr	67.283	84.705
Nb	2.242	1.529
Mo	2.5	2.5
Ag	-2.0	-2.0
Cd	1	1
Sn	-100	-100
Sb	1.10	3.00
Te	-10	-10
Cs	0.20	0.20
Ba	36.947	62.987
La	3.293	2.795
Hf	1.854	2.299
Ta	0.132	0.102
W	1	1
Ir	-50	-50
Au	1.0	1.0
Ce	9.038	8.744
Pr	1.414	1.483
Nd	7.369	7.892
Sm	2.329	2.682
Eu	0.983	1.041
Gd	3.444	3.698
Tb	0.581	0.627
Dy	4.264	4.692
Ho	0.865	0.976
Er	2.707	3.043
Tm	0.392	0.423
Yb	2.428	2.785
Lu	0.377	0.442
Th	0.567	0.437
U	0.1	0.3

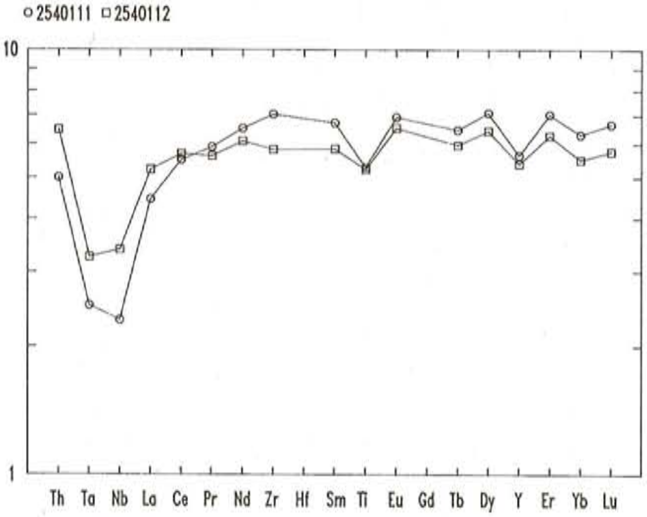


Figure 3. *Chondrite-normalized plot showing extended rare-earth-element (REE) patterns for pillow basalts. Sample 2540112 (BHOB-28-92) is from a 12 m raft in upper New Bay Formation debrites immediately northeast of Phillips Head. Sample 2540111 (BHOB-27-92), collected within the arc-related Phillips Head Igneous Complex (Figure 2), is shown for reference. Primitive mantle-normalization values, indicated logarithmically on the ordinate, are approximately twice chondrite.*

The transport of mature exotic clasts as turbidity current bedload, down a submarine channel into an area of unconsolidated sediment, could itself trigger debris flows, by increasing the shear stress of the sediment pile beyond its shear strength. Intimate mixing of exotic and intraformation material would occur during turbulence in the resultant debris flow, producing chaotic polymict debrites. Alternatively, it is possible that debris flows moved down an existing turbidite feeder channel, incorporating exotic clasts previously introduced to the channel-fill sequence as turbidity current bedload. The absence of erosive bases from the debrite units at Michael's Harbour favours the first model.

Similar processes were probably responsible for the introduction of exotic clast material into the submarine environment at Phillips Head, prior to redeposition by mass flow. The thickness of the Phillips Head debrite–olistostrome and the presence of large rafts points to sediment failure and redeposition on a larger scale than that seen at Michael's Harbour.

DEPOSITIONAL SETTING

The facies associations and depositional processes described above suggest one of two submarine settings; deep-water fan or slope apron.

Extensive debrites, the products of submarine debris flows and slides, are documented from ancient and modern deep-water turbidite fans (e.g., the modern Amazon and Rhône fans; see Pickering *et al.*, 1989, p. 174 *et seq.*, and references therein). Debrites are most commonly found in the upper and lower parts of fans (Stow, 1986, and references therein). They frequently fill upper fan channels, where they are interbedded with channel-fill sequences of coarse-grained, pebbly to conglomeratic sandstones. Lower fan debrites are usually interbedded with turbiditic argillites, thin hemipelagites, and laterally continuous turbidite sandstone beds. The presence of olistostromes in a debrite and fine-grained turbidite-facies association is more indicative of a slope apron setting (Stow, 1986). The facies associations of the upper New Bay Formation at Michael's Harbour could be interpreted in terms either of a lower fan or a slope apron setting. Olistostromes are more typical of slope aprons than deep-water fans, and the upper New Bay Formation at Phillips Head is therefore more likely to be a slope apron facies association.

The depositional environment of the upper New Bay Formation throughout the Bay of Exploits is probably a slope apron, but a lower fan setting cannot be ruled out. The presence of abundant pillow basalt, the geochemical affinity of the large raft of basalt lava and breccia at Phillips Head, and the similarity of the magmatic clasts to the arc tonalites and diorites of local igneous complexes suggest that the edifice skirted by the depositional slope may have been part of a complex marine volcanoplutonic arc.

DISCUSSION

Recent investigations into the relationships between Early and Middle Ordovician sedimentary and volcanic sequences along the northern edge of the Anglo-Welsh terrane of Eastern Avalonia are significant to the Iapetan evolution of the orogen's southeast margin, and for the New Bay Formation and the Exploits Group in particular. In northwest England, Middle Ordovician, mainly subaerial, volcano-sedimentary successions are interpreted to have formed in a continental destructive plate margin setting; these Llanvirn to Caradoc subduction-generated volcanic rocks probably accumulated within an intra-arc rift (Hughes and Kokelaar, 1993). However, the Tremadoc to early Llanvirn history of turbidite, olistostrome and slump-sheet deposition in northwest England (Cooper *et al.*, 1993) contrasts strongly with the late Tremadoc–early Arenig history of olistostromal melange, arc and ophiolite evolution in the Exploits Subzone (Swinden, 1990; Swinden and Fyffe, 1991).

In the Skiddaw Group of northwest England, deep-marine turbidite deposition and slump-related soft-sediment deformation occurred between the Tremadoc and the early Llanvirn (Hughes *et al.*, 1993). Subsequently, the Skiddaw Group rocks were regionally uplifted by magmatic doming, extensively denuded, and then unconformably overstepped by subaerial arc-volcanic sequences (Hughes *et al.*, 1993; Millward and Molyneux, 1992), with the result that substantial parts of the Skiddaw Group sequence are missing from some areas. In the Exploits Group of northeast Newfoundland, the entire New Bay Formation (ca. two kilometres in maximum thickness) is locally absent along both the northwestern and southeastern margins of the group, where back-arc and arc-volcanic rocks are directly juxtaposed (Figure 2 of O'Brien, 1991; Figure 2, *this paper*). This phenomenon has been historically explained by the occurrence of anomalously large amounts of stratigraphical separation across local thrust faults. However, by analogy with the Skiddaw Group, it is possible that the absence of the New Bay Formation from some areas may be explained by an unconformity (separating eroded or slump-transported Early Ordovician and overstepping Middle Ordovician rocks) that has been obscured by thrust faulting.

Although undated, the upper New Bay Formation was presumably deposited sometime after the precipitation of a limestone (exotic clast) of known early-mid Arenig age (Hibbard *et al.*, 1977). Accumulation had ceased before the deposition of the earliest Llanvirn part of the Strong Island Chert (Williams *et al.*, 1992a), the latter belonging to the back-arc succession of the Exploits Group (Dec *et al.*, 1992; Figure 2). The edifice, which is interpreted as having flanked the tectonically active New Bay basin, could have been a pre-arc microcontinental fragment (e.g., Evans *et al.*, 1990; O'Brien *et al.*, 1991) situated along the Gondwanan margin of Iapetus. However, the ensimatic nature of the known pre-Middle Ordovician arc-volcanic sequences in the Exploits Subzone (Swinden, 1990) would favour the notion that the uplifted feature is more likely to be an exhumed volcanoplutonic Iapetan arc complex. Any combination of erosion, resedimentation and non-deposition could have taken place at or below the marginal slope of such an edifice, and led to the development of the sedimentological and stratigraphical features of the upper New Bay Formation discussed in this paper.

CONCLUSIONS

The deep-marine depositional environment of the late Early to earliest Middle Ordovician strata of the upper New Bay Formation of the Exploits Group is considered to be either slope apron or lower turbidite fan. Syndepositional transport occurred on a large scale and was associated with the reworking of both intrabasinal and polycyclic extrabasinal material. Arc basalts, which may have comprised part of an exhumed Iapetan volcanoplutonic complex, provided detritus to the deep-sea environment. The relationship of the analyzed detrital basalt to the arc-related rocks within and near the Exploits and Wild Bight groups remains uncertain.

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