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GEOLOGY OF THE CUTWELL GROUP, NOTRE DAME BAY, NEWFOUNDLAND: A DISRUPTED VOLCANIC–VOLCANICLASTIC ISLAND-ARC COMPLEX

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ABSTRACT

The rocks of the Cutwell Group record a three-stage structural history. The first deformation (D_1) is Llanvirn or earlier, and resulted in northeast-directed thrusting and folding related to the sinistral strike-slip on the Long Tickle Fault. The second deformation (D_2), of presumed Late Ordovician age, resulted in northwest-directed thrusting in response to a sinistral oblique-slip on the Long Tickle Fault. The third deformation (D_3), which also includes rocks of the Silurian Springdale Group, resulted in a dextral strike-slip faulting on the Lobster Cove and Crescent Lake–Tommy's Arm faults.

The rocks of the Cutwell Group are divided into three lithofacies: the tuff lithofacies, the lapilli tuff–tuff breccia lithofacies, and the primary volcanic lithofacies. The observed facies variations are consistent with the formation and evolution of the group in an island-arc setting.

Volcanogenic sulphide mineralization and alteration are related to pulses of felsic volcanism. Correlation of the mineralized felsic sequences with the apparently barren felsic rocks elsewhere in the group, suggests that the latter should have similar mineral potential.

INTRODUCTION

Detailed field studies of the Cutwell Group in the Notre Dame Bay area, north-central Newfoundland, have been carried out as part of the project, 'Metallogeny of the Buchans–Roberts Arm Belt'. The object is to determine the metallogeny of non-ophiolitic rocks in the western Dunnage Zone, and this report summarizes the results of the second field season.

The Cutwell Group was defined by Kean (1973), based upon the detailed mapping of Long Island (Figure 1). He divided the Cutwell Group into seven stratigraphic units: six formations and one igneous complex, and interpreted the units as forming a continuous, over 5-km-thick, south-facing sequence. In addition, based on the chemical composition of volcanic rocks and on the observed stratigraphy, the Cutwell Group was inferred to represent an island-arc volcanic sequence, which recorded the transition from an immature to mature arc (Kean, 1973; Kean and Strong, 1975). Further, on the basis of the fauna from thin limestone lenses within volcanic rocks on the west shore of Little Bay Island and along the southern shore of Long Island, the Cutwell Group was tentatively assigned to the Middle Ordovician (Williams, 1962; Strong and Kean, 1972).

A Caradocian, fossil-based age for the black shale from the middle of the Cutwell Group was obtained by Dean (1977, 1978). He included the formation underlying the black shale in the pre-Caradocian 'immature island-arc' sequences, and the formations overlying the shale, in post-Caradocian 'mature island-arc' sequences. The deduced post-Caradocian age of the rock sequences in the southern part of the island was contradicted by an upper Arenig–lower Llanvirn age, indicated by the shelly fauna and conodonts from limestone beds on the southern shore of the island (Stouge, 1980). These conflicting ages suggest that there are major structural problems with the Cutwell Group, and these contradictions have to be resolved before a firm stratigraphy can be established.

Szybinski (1988) re-mapped the Cutwell Group and showed that it has been structurally disrupted. The structural style of the group was shown to be a relatively complicated thrust system, and the previously developed stratigraphic succession represents a series of structurally repeated lithological units. During the 1988 field season, survey work was concentrated on Long Island with the following objectives: 1) consolidating the stratigraphical and structural interpretations, 2) comprehensively documenting the structural boundaries between the units, and 3) to determine the correlation of the mineralized sequences with rocks elsewhere in the group.

REGIONAL GEOLOGY

The Cutwell Group lies within the Notre Dame Subzone of the Dunnage Zone (Williams *et al.*, 1988), which records the Cambrian and Ordovician history of the oceanic realm, commonly referred to as Iapetus. Rocks of the Cutwell Group

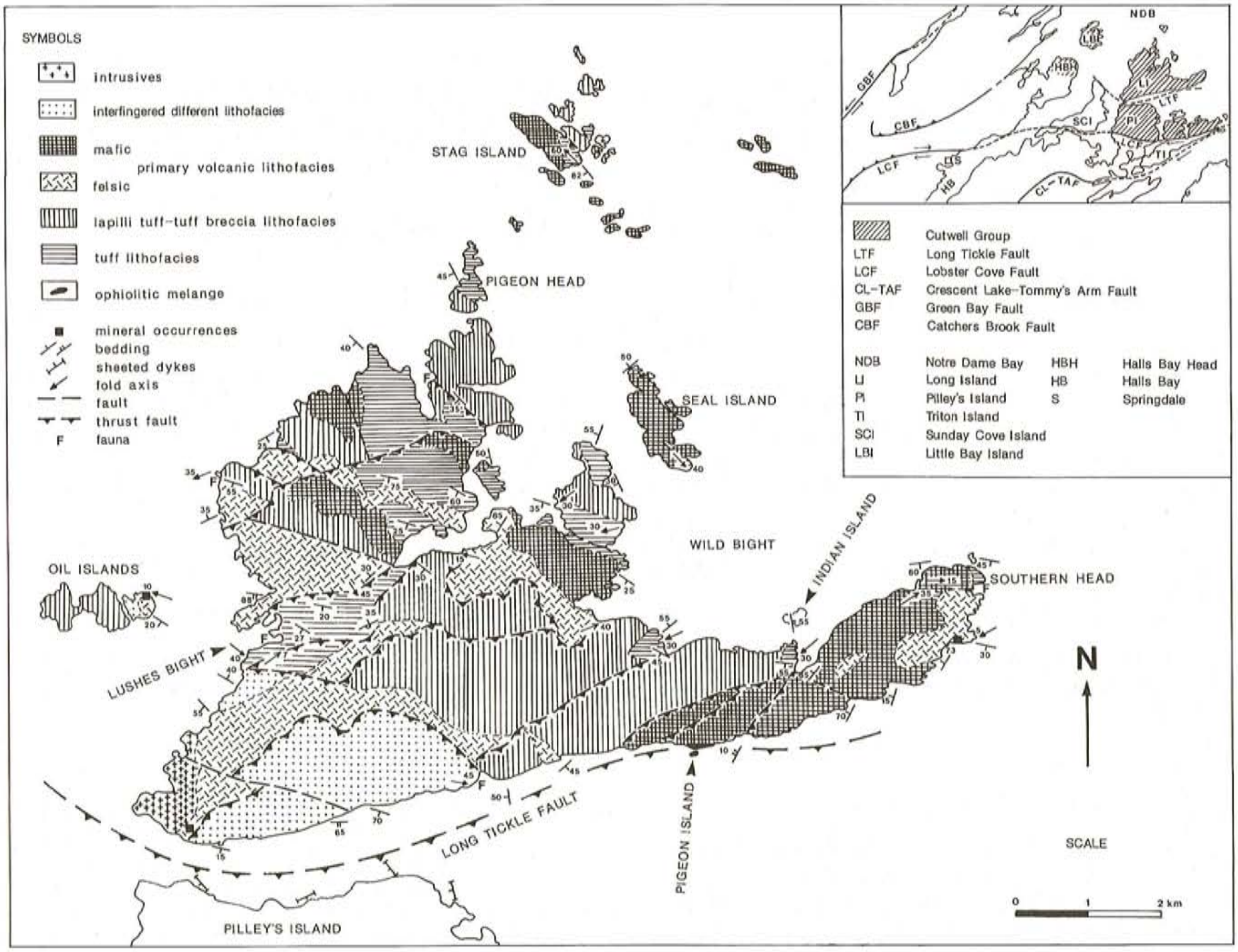

Figure 1. *Generalized geology of the Cutwell Group on Long Island.*

outcrop in western Notre Dame Bay, from the western shores of Halls Bay Head to the eastern end of Triton Island (Figure 1). Contacts with adjacent groups are faulted and two faults are of regional importance. The Lobster Cove Fault, a large strike-slip fault system (Szybinski, 1988; Calon and Szybinski, 1988) separates the Cutwell Group from the Lower Ordovician Roberts Arm Group on Pilley's and Triton islands. The Long Tickle Fault, an oblique slip fault, divides rocks of the Cutwell Group on Long Island, from sheeted dykes and pillow lavas of the Lushs Bight Group on Pilley's and Sunday Cove islands (Figure 1).

STRUCTURAL GEOLOGY

A preliminary compilation of the 1987 field data (Szybinski, 1988) showed that the volcanic rocks of the Cutwell Group were affected by two major deformational events; an older event, which resulted in extensive, north-directed thrusting and a younger event, which was recorded by major, strike-slip, dextral movement on the Lobster Cove Fault.

Re-examination of field data, deformation microstructures in oriented samples and an extensive kinematic study on Long Island and adjacent islets during the 1988 season, revealed that the deformational history of the area is more complex than originally thought and that the rocks of the Cutwell Group record at least two events of north-directed thrusting:

1) D_1 event, during which northeast-directed movement was associated with sinistral strike-slip on the Long Tickle Fault; and

2) the D_2 event, a northwest-directed thrusting and high-angle reverse faulting related to sinistral oblique slip on the Long Tickle Fault, which utilized some of the previously developed structures.

The latest deformational event, D_3, is recorded by dextral strike-slip on the Lobster Cove and Crescent Lake–Tommy's Arm faults, and may be related to movements on the Green Bay Fault.

The D_1 Event

The northeast sense of movement obtained from some kinematic indicators (e.g., orientation of fold hinges and fold vergence, shear bands and slickensides), in the central and northern part of Long Island may be explained by and is compatible with, sinistral strike-slip movement on the Long Tickle Fault. The Long Tickle Fault divides Long Island from Pilley's Island and the trace of this fault is mainly offshore.

Several folds within rocks of the Cutwell Group exhibit a 'soft-sediment' style of deformation, e.g., within the shale–limestone breccia–greywacke broken unit, on the southern shore of Lushes Bight Harbour or in tuffaceous rocks of the Wild Bight area (Plate 1). The relative consistency of the fold orientations with respect to orientation of cleavage in the immediate area, suggests that the folds may be valid kinematic indicators (Agar, 1988), and are assigned to the D_1 event. Northeast-directed movement is also deduced from deformation within the shaly mélange on Seal Island.

Plate 1. *'Soft-sediment' style of folding of mafic tuffs, Wild Bight area (looking southeast).*

Mafic dykes, acting as feeders to andesitic flows, cut through already deformed strata in the Wild Bight area. The andesitic flows that are laterally extensive, overlie shales and argillites of upper Arenig age (S.H. Williams, personal communication, 1988) on Southern Head. This and the presence of 'soft sediment' style folds in lower Llanvirn strata, allows the possibility that the age of first deformation may be Arenig–lower Llanvirn.

Locally, well developed S_1 axial-planar cleavage is overprinted by regional S_2 cleavage (Plate 2), and is related to the D_2 event.

The D_2 Event

The Long Tickle Fault on Long Island brings rocks of ultramafic basement(?) against rocks of the Cutwell Group. Ultramafic rocks are exposed on the southern shore of Long Island and on Pigeon Island, a small offshore island (Figure

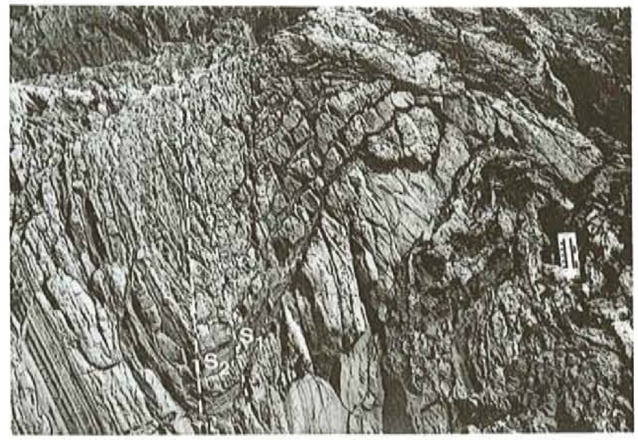

Plate 2. *F_1 fold with well developed S_1 axial-planar cleavage overprinted by S_2 cleavage, Wild Bight area (looking east).*

1) and are predominantly metasomatic magnesite-rich mylonites. These mylonites and an ophiolitic mélange form a small-scale strike-slip exotic duplex (Woodcock and Fischer, 1986), which remains attached to the footwall. Mylonites within this duplex, exhibit locally well developed shear bands (C-surfaces; Berthé *et al.*, 1979), the geometry of which suggests development in sinistral oblique slip.

Structures compatible with sinistral oblique-slip are found immediately north of the Long Tickle Fault and across Long Island. The intensity of deformation related to this event (D_2), decreases toward the north. The D_2 deformational event is responsible for the present distribution of the lithostratigraphical units (Figure 1).

The D_3 Event

The geometry and sense of movement on the Lobster Cover Fault clearly show it to be a complex structure probably related to movements on the Green Bay Fault. The fault has commonly been interpreted on the basis of regional geology, as a folded, south-directed thrust fault (Dean and Strong, 1977). Contrary to this interpretation, deformation structures in Silurian red sandstones along the lineament on Sunday, Pilley's and Triton islands, indicate that it is a dextral strike-slip fault (Szybinski, 1988; Calon and Szybinski, 1988). This structure appears to truncate (at a very low angle) an earlier thrust system and sinistral oblique-slip shear zones (D_2). The Lobster Cove Fault changes in its geometry and orientation along the length of the structure. In the Springdale area, it forms a large-scale bend and grades from strike-slip in the east to oblique-slip and finally to a southeast-directed thrust in the west. In the latter area, rocks of the Lower Ordovician Catchers Pond Group are brought upon volcanics of the Silurian Springdale Group (Jenner and Szybinski, 1987).

Recently, Blewett and Pickering (1988) stressed the importance of sinistral shear during the Acadian Orogeny in north-central Newfoundland. Their interpretations and conclusions were based on field observations in the area, immediately to the south of the Lobster Cove Fault. For this reason, structural observations have been extended south of the Lobster Cove Fault into the Roberts Arm Group and the shear zone of the Crescent Lake—Tommy's Arm Fault, which form the southern shore of Triton Island. Field studies revealed close similarities in the structural history of both faults. The vergence of well developed vertical folds along this lineament indicate clearly a dextral sense of shear. However, evidence for northeast-directed thrusting and sinistral strike-slip have been found within shear zones transected by both dextral strike-slip faults.

Age of the D_2 and D_3 Events

There is some evidence to establish the relative and absolute ages of the D_2 and D_3 events. The D_3 dextral strike-slip is the youngest deformational event in the area and is at least Silurian or younger, since it incorporates the red sandstones and conglomerates of the Silurian Springdale Group. The Lobster Cove Fault postdates the D_2 event because it truncates the shear zones related to this event on Triton, Pilley's and Sunday Cove islands.

The lower age limit of the D_2 event may be determined from the youngest strata involved in the thrusting, which is of middle Llanvirn age (O'Brien and Szybinski, 1988). The upper age limit on the D_2 thrusting, in the Cutwell Group, is considered to be Late Ordovician, since Silurian strata appear not to be involved.

However, it is possible that structures assigned to the D_2 and D_3 deformational events may represent one and the same event.

STRATIGRAPHY

The structural model developed for the Cutwell Group in this paper disagrees with the previous stratigraphy established and formalized by earlier workers (Kean, 1973; Kean and Strong, 1975; Dean, 1977, 1978). In particular, units representing the same stratigraphic level, reappear in the different thrust slices of the formalized stratigraphy (Szybinski, 1988). For this reason, the previously established formal stratigraphical nomenclature is abandoned, and until the Cutwell Group is redefined and a new stratigraphy erected, it is discussed in terms of its lithofacies.

Age Criteria

Correlation of units between different thrust slices have been facilitated by the presence of abundant identifiable microfossils, in particular, conodonts and graptolites. Preliminary identification of the collected conodonts (O'Brien and Szybinski, 1988; F. O'Brien, personal communication, 1988) and graptolites (Williams, 1988; S.H. Williams, personal communication, 1988), has been sufficient to establish the validity of the structural model. Assemblages of the fauna of similar lower to upper (?) Llanvirn age were obtained from several scattered outcrops across the island revealing repetition of the stratigraphy. Dunning and Krogh (1988) have obtained a U—Pb zircon age of 469^{+5}_{-3} Ma, for a felsic tuff overlying the sedimentary fossiliferous unit of lower Llanvirn age, on Oil Island, which confirmed the fauna-based age. Older fossiliferous strata of upper Arenig age (S.H. Williams, personal communication, 1988) have also been found in the area and may be traced from Southern Head up to Pigeon Head, north of Long Island. The evolution of the volcanic centre(s) forming the Cutwell Group on Long Island covers a time span of at least upper Arenig to upper (?) Llanvirn. Lateral correlation of the Cutwell Group with the Buchans Group is suggested by the age and the assemblages of conodonts present within the felsic sequences.

Lithofacies

The rocks of the Cutwell Group on Long Island are divided into three lithofacies (Busby-Spera, 1988): 1) the tuff lithofacies; 2) lapilli tuff—tuff breccia lithofacies; and 3) the primary volcanic lithofacies.

The Tuff Lithofacies. The tuff lithofacies consist of finely laminated, cherty black shales interbedded with green reworked tuff (turbidite) and grey cherts. Locally, thin beds of greenish-black feldspar—phyric tuff are present in the upper part of this sequence. Intercalated horizons of welded to nonwelded dacitic pyroclastic flows are a common occurrence that cut down into pre-existing lithologies, and contain a large amount of shale and chert rip-ups (Plate 3).

The Lapilli Tuff—Tuff Breccia Lithofacies. The lapilli tuff—tuff breccia lithofacies is often inter-stratified with rocks of the tuff lithofacies. It consists of a variety of volcanic fragments up to 0.8 and 1 m in diameter, in a fine- to medium-grained tuffaceous matrix. The most common clasts are of plagioclase-phyric and clinopyroxene-phyric mafic volcanic and subvolcanic rocks, as well as felsic lithologies. Highly silicified and epidotized fragments occur and may indicate strong synvolcanic (prior to deposition) alteration. Locally, isolated blocks or clusters of blocks of limestone are present within this lithofacies. The variety of fragments within the lapilli tuff—tuff breccia lithofacies indicates mixing of volcanic debris, and is interpreted as being deposited from debris flows. Some of the debris flows, scoured channels in underlying rocks of the tuff lithofacies and contain rip-up fragments of the tuff lithofacies.

The Primary Volcanic Lithofacies. The primary volcanic lithofacies is diverse and includes dacitic domes and related subvolcanic intrusives, felsic tuffs and tuff-breccia, and mafic, basaltic to andesitic, massive and pillowed flows and pillow breccias.

Dacitic volcanic rocks vary from flow and intrusive phases of banded dacite to structureless plagioclase-phyric tuff. Locally, these phases are difficult to distinguish from highly altered mafic rocks. Felsic rocks are usually light green to buff and when associated with sulphide mineralization, they are yellow to rusty.

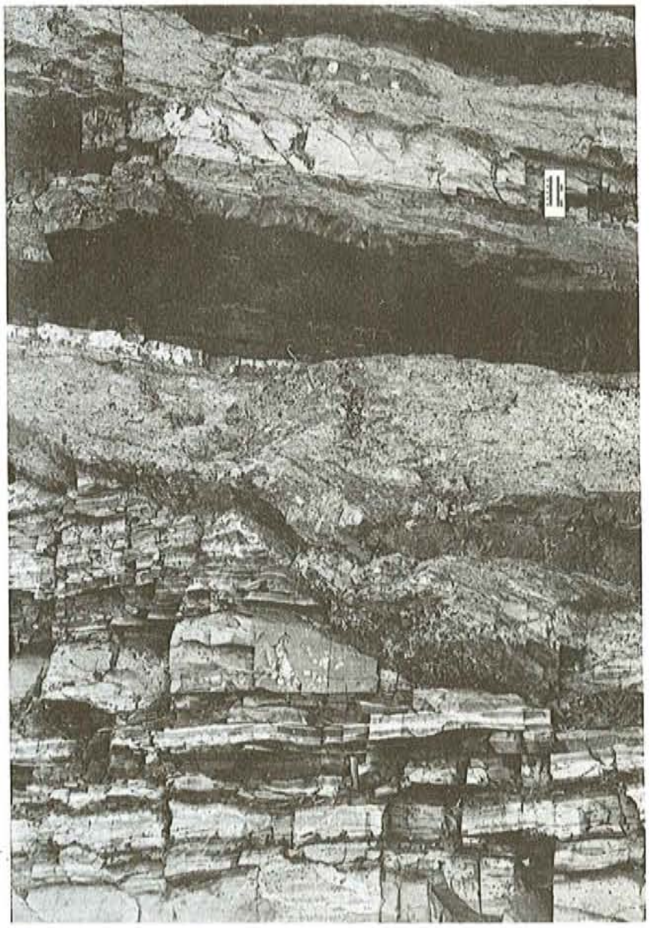

Plate 3. *Partially welded dacitic pyroclastic flow showing shale and chert rip-ups, cutting down into strata on Southern Head.*

The Southern Head area appears to represent part of a felsic dome, overlying mafic lavas, breccia and hematitic tuff. Flows, oligomictic felsic tuff breccia and slump folds have been recognized within dacitic rocks immediately overlying the mafic basement. A dacitic intrusive phase of the dome intrudes the underlying mafic rocks. A large dacitic feeder dyke, is also exposed, and is associated with an intrusive breccia of dacitic clasts and argillite and shale fragments.

Dacitic rocks (flows and pyroclastics) in the central and western parts of Long Island are associated with subvolcanic intrusives. The lens-like shape of the outcrops suggests that they may too represent fragments of dome(s).

Basaltic to andesitic, massive to pillowed flows and pillow breccias are a volumetrically important component of this lithofacies (Plate 4). They vary from aphanitic and clinopyroxene-rich basalt to plagioclase-phyric andesite. Massive flows often grade vertically into pillowed flows. Interpillow material is usually green to red chert. On Stag and Seal islands, hyaloclastite and tuffaceous limestone is often found between pillows. The ratio of massive or pillowed

Plate 4. *Pillow-breccia and mafic sheet-flow (delineated) on southern shore of Long Island.*

flows to volcaniclastic rocks varies across the island; in the northeastern part of the island the ratio is high whereas in the southwest, it is low.

Stag Island Breccia

Stag Island and several islands in the vicinity are partially underlain by breccia, consisting predominantly of angular clasts of coarse-grained gabbro, diabase and granodiorite. Often, the breccia interfingers with, or is overlain by, pillow basalt. Locally, this lithology is intruded by plugs of gabbro and diabase dykes.

The stratigraphic position of the Stag Island breccia has not as yet been established, nor has a similar lithology been found elsewhere on Long Island. However, there is an outcrop of mafic tuff with angular clasts of coarse-grained gabbro, on the southeastern shore of Little Bay Island. These rocks seem to be structurally above (stratigraphically below ?) the unit, which contains limestone breccia of upper Arenig–lower Llanvirn boundary age (F. O'Brien, personal communication, 1988). If the correlation of these units is valid, then the breccia, associated pillow basalt and intrusives, form the oldest unit on Long Island. They may form the arc (?back arc) basement on which the volcaniclastic and primary lithofacies were deposited, in agreement with the model proposed by Kean (1973).

MINERALIZATION

Volcanogenic Sulphides

Several volcanogenic sulphide occurrences are found in the Cutwell Group, however, only two occurrences, the Oil Island and Shamrock, are of economic interest. The lack of good exposure especially of the Shamrock prospect, makes it difficult to determine the origin of mineralization. There is, however, an excellent outcrop of sulphide (predominantly pyrite) mineralization associated with dacitic volcanic rocks in the Southern Head area. Dacitic flows and pyroclastics overlie highly altered (chloritization–seritization) tuff, interbedded with hematite and magnetite-rich siliceous 'exhalite'. Pyrite forms the matrix in a strongly altered zone of brecciation, which is present within the dacitic rocks. The alteration zone is cut by an unaltered mafic dyke similar to the underlying pillow lava. This would suggest that both, mineralization and alteration, may be related to the exhalative processes associated with pulses of felsic volcanism. The presence of significant 'footwall' alteration along the northeastern shore of Long Island and the presence of mineralized welded dacitic pyroclastics within the shale-argillite sequence, together with the presence of a hematitic, siliceous 'exhalite' horizon, suggest an environment favourable for the deposition of massive sulphides.

Mineralized Veins

Several extensional quartz and calcite veins that have associated mineralization have been mapped in the Wild Bight area. These veins appear to be 'postkinematic', and are not related to Ordovician volcanism. Two kinds of veins predominate: 1) calcite veins with pyrite, sphalerite and galena, and 2) quartz veins with chalcopyrite, pyrite, galena, sphalerite and secondary malachite.

The veins are scattered over the entire area, but there are no larger scale mineral occurrences associated with them; they may be related to the Silurian or Devonian intrusive events.

Importance of Structural and Lithofacies Studies

Most volcanogenic massive sulphide deposits (VMS) in central Newfoundland are geograhpically associated with felsic volcanic rocks, and, like most VMS, are stratabound. In general, the mineralization is related to felsic domes and pyroclastic rocks, which occur in a restricted stratigraphic interval. However, structural complexity often obscures this simple relationship, e.g., in the Buchans camp.

In the Cutwell Group, there are several exploration targets that have characteristics found in VMS deposits. Both the structural and lithofacies analysis carried out in this study can be used to delineate the most favourable horizons for exploration. The structural model, here proposed for the Cutwell Group, is clearly important for any exploration program, since it is not possible to extrapolate the location of any favourable horizon using a layer-cake stratigraphic model.

SUMMARY

Field work resulted in new insights into the structural development of the western Notre Dame Bay area, and an informally revised stratigraphic succession of the Cutwell Group.

The conclusions based on this work include the recognition of three deformational events related to generally continuous sinistral transpression in the area. This resulted in two stages (D_1 and D_2 events) of the generally north-directed thrusting on Long Island associated with sinistral strike- and oblique-slip on the Long Tickle Fault. A final, late D_3 event resulted in dextral strike-slip on the Lobster Cove and Crescent Lake–Tommy's Arm faults.

The rocks of the Cutwell Group on Long Island are divided into three lithofacies:

1) the tuff lithofacies, comprising tuffaceous cherts, fine to sandy textured, reworked tuffs, locally interbedded with pyroclastic, partially welded flows,

2) the lapilli tuff–tuff breccia lithofacies comprising a variety of volcanic fragments in a fine- to medium-grained tuffaceous matrix, interpreted as deposited from debris and pyroclastic flows, and

3) the primary volcanic lithofacies comprising dacite domes, pyroclastics and intrusive phases, basaltic to andesitic massive and pillowed flows, and pillow breccias.

It has been recognized that volcanogenic sulphide mineralization and hydrothermal alteration on Long Island are associated with felsic volcanic rocks. These rocks, although only locally mineralized, seem to correlate with apparently barren felsic volcanics elsewhere in the stratigraphy. The already known occurrences, significant alteration and the presence of an hematitic 'exhalite' horizon, may be indicators that mineral deposits remain to be discovered on Long Island. This, and new information about the structure and informally revised stratigraphic succession, may provide the impetus for further exploration of the Cutwell Group.

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