THE SOUTHWEST PORTION OF THE DUNNAGE MELANGE AND ITS RELATIONSHIPS TO NEARBY GROUPS

JAMES P. HIBBARD

THE SOUTHWEST PORTION OF THE DUNNAGE MÉLANGE AND ITS RELATIONSHIPS TO NEARBY GROUPS

by

James P. Hibbard

A Thesis
Submitted in Partial Fulfillment
of the Requirements for the Degree of
MASTER OF SCIENCE
Memorial University of Newfoundland
1976

FRONTISPIECE: View south over Powderhouse Cove and Masons Cove

"dunnage 'den-ij n (origin unknown) 1: loose materials used around a cargo to prevent damage; also, padding in a shipping container to protect contents against breakage. 2 BAGGAGE."

Webster's 7th New Collegiate Dictionary

ABSTRACT

The Dunnage Mélange is typified by slumped blocks of clastic sediment and mafic volcanics set in a dark shale matrix. It outcrops for 40 km. southwestward from its type area in Dildo Run, with a maximum outcrop width of 13 km. Previous work has been confined to the Dildo Run area, where the interpretation of stratigraphic relationships of the Dunnage Mélange and surrounding units has been controversial. The present study focusses on the southwest portion of the mélange in an attempt to resolve this controversy as well as to investigate the character and extent of this portion of the mélange.

The southwest portion of the mélange overlies and interdigitates with the gabbro-infested, Ordovician New Bay Formation. The mélange contains gabbro blocks that are confined to the area proximal to this transition zone. Similarly, in the northwest portion, the largest mafic volcanic blocks define a wide zone that is correlative westwards with the Lawrence Head Volcanics of the Exploits Group. Along its northwest border, the Dunnage is locally conformable with Caradocian or later, shale and greywacke units, though in most places this contact is fault-modified. These relationships imply that the Dunnage is an easterly chaotic equivalent to part of the Exploits Group.

The chaotic nature of the mélange can be attributed primarily to discontinuous, dominantly extensional, soft rock deformation of strata due to massive slumping. This possibly occurred as a single progressive event and involved rocks in various stages of lithification. Forces responsible for soft rock deformation existed from New Bay depositional time until the Lower Silurian, intensifying prior to the Caradocian, following which they decreased and terminated. The chronology of later

penetrative events is uncertain, though most hard rock structures are presumed to be Devonian, as flat lying Carboniferous strata occur elsewhere in the Exploits Zone.

Regional relationships indicate that the Dunnage Mélange occupied a basin on the southeast flank of a Lower Ordovician island arc complex. Previous workers have viewed this fact to indicate that mélange formation was related to an active, west dipping, subduction zone. The present study reveals that no valid criteria exist for interpreting the mélange terrane to have occupied an active trench. Rather, the tectonic position of the mélange and its apparent synchroneity with other Newfoundland mélanges suggest it was a massive slump during widespread Taconic events, though the direct cause of slumping remains ambiguous.

TABLE OF CONTENTS

LIST OF FIGURES

Page

LIST OF PLATES

I. INTRODUCTION

1-1 Location and access

The thesis area is located in the Bay of Exploits, northeastern Newfoundland (fig. 1). Its southern margin is near the Brown's Arm-Lewisporte Road (rte. 54) and the Lewisporte-Campbellton Road (rte. 41). To the north, it is bounded by an approximately east-west line from the northern tip of Upper Black Island to the northern end of Knight's Island. It extends eastward to the Comfort Cove Peninsula and westward to Thwart Island and Upper Black Island. The latter two islands were visited only briefly, as their geology is adequately reported by others (Oversby, 1967; Franks, 1974). Thus the map area covers approximately 300 km^2 dominated by coastline.

Access to the area has been facilitated in recent years by road improvement and construction. Lewisporte, the major population center, is situated equidistant (56 km) from Grand Falls and Gander. Approach from either town may be made along the Trans-Canada Highway, departing north from the highway at Notre Dame Junction on the Road to the Isles (rte. 41). Lewisporte is also serviced by Canadian National coastal boats.

Field work in the area is facilitated by use of a small boat, as islands constitute approximately two-thirds of the terrane, and locally dense vegetation extends to the rugged shoreline.

1-2 Climate and topography

The summer climate is generally mild and pleasant. Rainfall is frequent, though rarely accompanied by fog, while the summer temperature is very close to 15°C, and the prevailing winds are from the southwest.

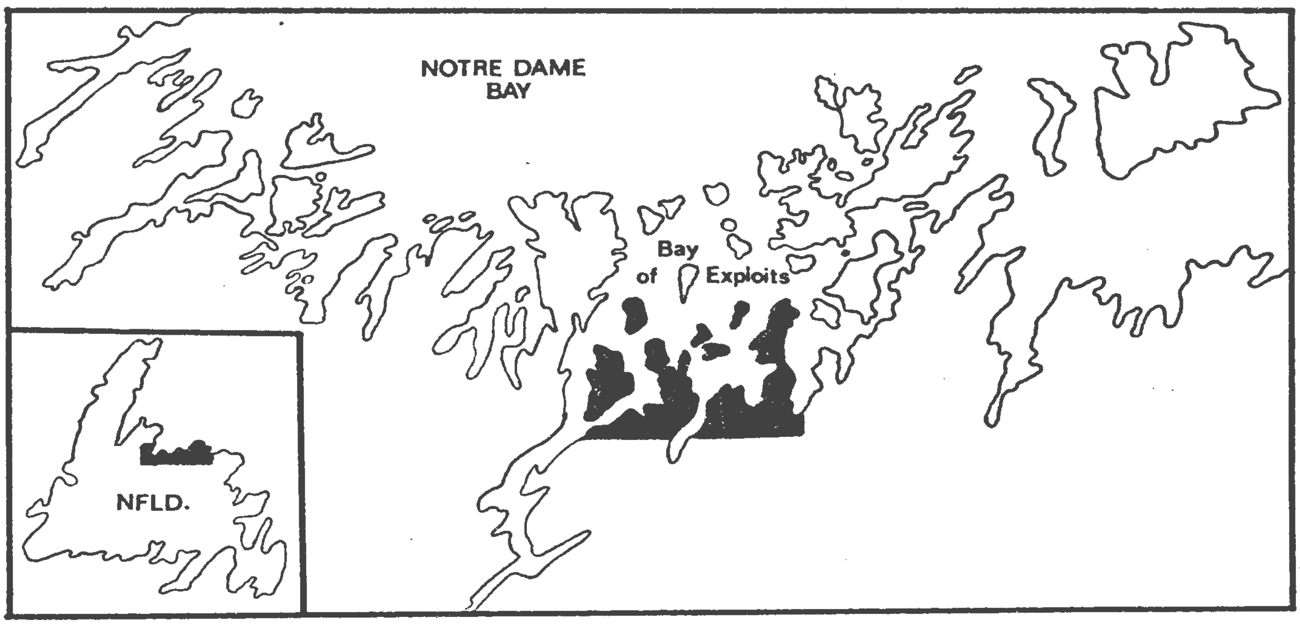


Figure 1: Location of the field area

The area is dominated by a uniformly random distribution of hills and ridges that locally rise abruptly from the surrounding boggy lands, giving a hummocky aspect to the region. Ridges and hills are almost exclusively underlain by gabbroic intrusions in the southern areas, whereas to the north these features reflect "knockers" of resistant greywacke and volcanic rocks within a melange terrane. The highest elevation in the area is 143 meters on Upper Black Island. The coastline is equally as variable as the topography, with many irregular embayments and headlands. Soft black shale is commonly found in re-entrants, whereas headlands are composed of resistant gabbro, granite or volcanic rocks.

Vegetation in the area is almost exclusively dense intergrown stands of softwood scrub. Locally, small lakes occur, though sphagnum bogs are much more abundant. In places, these are aligned in a northeast direction, parallel to bedrock structures.

1-3 Glacial geology

Trends of glacial grooves and striae indicate that the most recent ice movements were toward the north (fig. 2). Scattered roche moutonées also trend northerly.

Anorthosite erratics that occur at Foulke Cove and at Stanhope have no immediate southern source area, suggesting earlier southeast transport by glacial ice from the Grenville inlier of the Long Range Mountains or from Labrador.

Raised beaches are found in the area at Foulke Cove, Birchy Tickle and the southern tip of Knight's Island. These may represent the "climatic optimum" between the last glaciation and present (Brückner, 1973).

1-4 Geologic setting

The Dunnage Mélange is centrally situated in the Paleozoic Central Mobile Belt of the Newfoundland Appalachians (Williams, 1964). The Central Mobile Belt consists chiefly of Ordovician and Silurian volcanic and sedimentary rocks that display a complex stratigraphy and intricate structural relationships. It is flanked on either side by Lower Paleozoic platformal deposits that locally overlie Precambrian basement, and it is separated from the platforms by narrow belts of ultramafic rocks at Baie Verte and Gander River. Deformational effects are mild in the interior parts of the Central Mobile Belt relative to marginal orthotectonic zones at Fleur de Lys and Gander.

To facilitate understanding of the complex geologic relationships of the Appalachian structural province, Williams et. al. (1972, 1974) subdivided the system into nine zones, A through I, based on stratigraphy and structural style. Zones B through G represent the Central Mobile Belt. The Dunnage Mélange is located within zone E, the Exploits Zone, which is confined to the Newfoundland Appalachians (fig. 3).

The Exploits Zone is bounded to the northwest by the Lukes Arm-Lobster Cove Fault and to the southeast by the Reach Fault. Its inland extension is not well defined. The dominant structural trend is north-east, except along the north coast where the trend changes to a more easterly direction, apparently mimicking the Hermitage Flexure (Williams et. al., 1970).

The most prominent feature of the Exploits Zone is the Dunnage Mélange (Kay and Eldredge, 1968) that occupies a wide belt at its northern extremity. The mélange is a chaotic mixture of nearby Ordovician lithologies and locally it forms the base of the Ordovician-Silurian Exploits Group (Helwig, 1969). This group is grossly typified

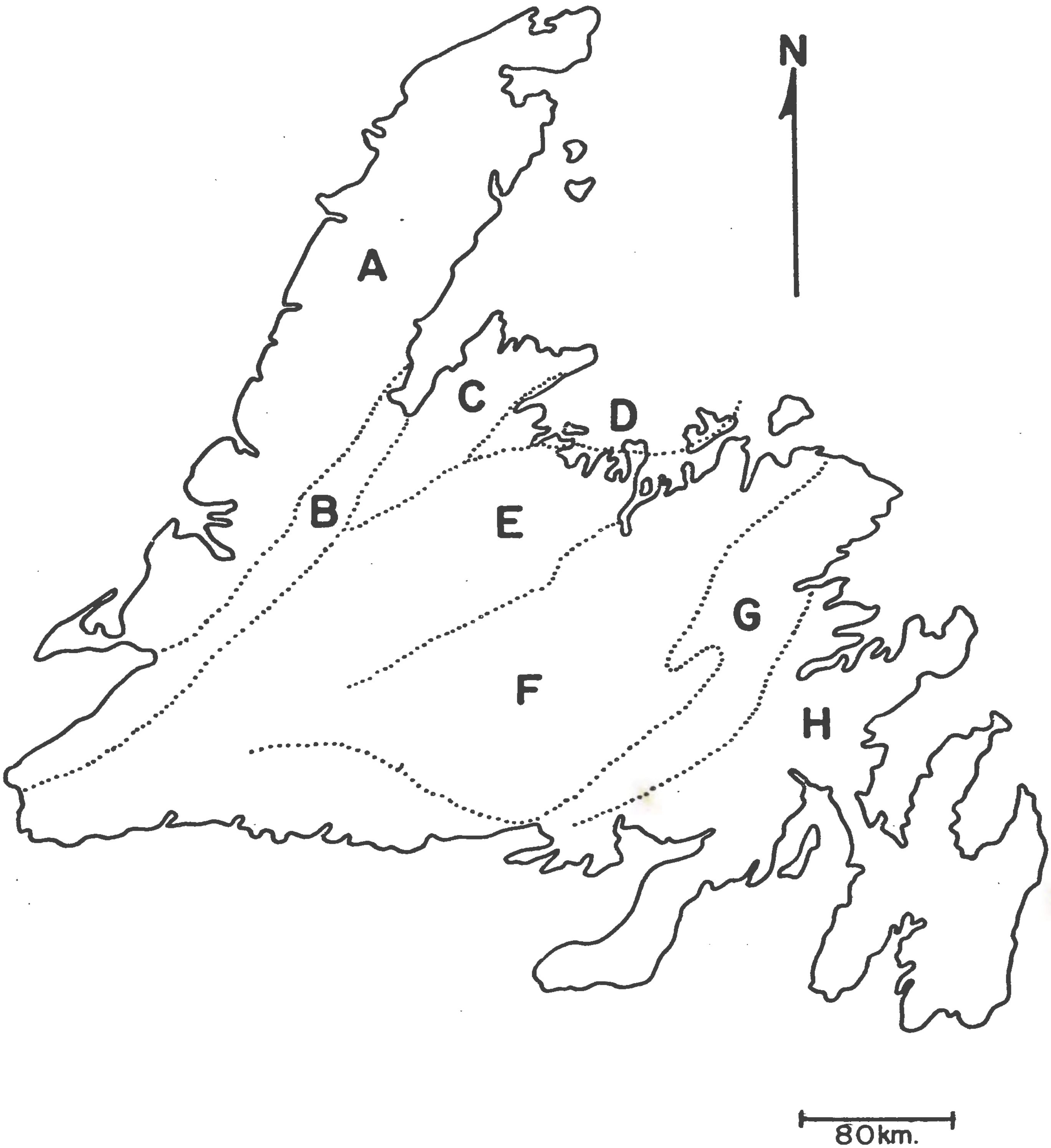


Figure 3: The tectonostratigraphic zones of the Newfoundland Appalachians (after Williams, et. al., 1972)

by thick Early Ordovician basic volcanic rocks overlain by Caradocian black shale and a clastic flysch sequence. The flysch sequence ranges in age from Middle Ordovician to Early Silurian, increasing in coarseness towards its top. In places, the Ordovician section is slumped and chaotically disposed, though nowhere as extensively as in the Dunnage Mélange. The overlying flysch sequence, mainly of Silurian age, appears to represent the infilling of an earlier deep marine basin.

Gabbroic and granitic intrusions are characteristic of the Exploits Zone. The gabbros are mainly sills that are folded with Lower Ordovician strata, and are probably of Ordovician age. Granitic intrusions cut Ordovician and Silurian strata as dikes and batholiths, with narrow contact metamorphic aureoles. These are believed to be of Devonian age. Lamprophyre dikes that are common in the thesis area have been dated as Jurassic-Cretaceous throughout Notre Dame Bay (Wanless et. al., 1965, 1967).

A steeply-dipping northeast-trending penetrative cleavage is displayed by the less competent rocks of the Exploits Zone. Locally, this cleavage is kinked. The major structural events of the Exploits Zone terminated prior to the Late Paleozoic, as inland, Carboniferous strata are flat-lying.

1-5 Previous work

The earliest workers in the Bay of Exploits were the indefatigable Jukes (1842; as termed by Milne, 1877) and Alexander Murray. Their work forms the staunch foundations of Newfoundland geology. Geological investigations carried out by these workers during the mid to late nineteenth century were of a gross reconnaissance nature. At that time, the Bay of Exploits strata were correlated with the Ordovician Quebec

Group (Murray and Howley, 1881).

Detailed studies were not undertaken until Heyl's investigation of the Bay of Exploits in 1936. Heyl was the first to separate and date the sedimentary and volcanic rocks, which he assigned to the Exploits Series. He also recognized the Lukes Arm Fault, which he interpreted as a high angle thrust fault that disrupted the Ordovician-Silurian strata. Due to the complexities inherent in a eugeosynclinal sequence and the difficulty of working in virgin territory, Heyl did not recognize the mélange terrane, and locally his formations were in reverse order. These and other irregularities in the details of his stratigraphy have led to the abandonment of the original Exploits Series, and its redefinition as the Exploits Group (Helwig, 1969).

The mélange terrane remained unrecognized for the next twenty years. During that period, Twenhofel and Schrock (1937) and Twenhofel (1947) attempted to clarify the Silurian stratigraphy of Newfoundland and in the process discovered many new fossil localities within Notre Dame Bay. Later investigations by Kranck (1952) encompassed reconnaissance mapping of the area between Lewisporte and Loon Bay as well as other areas nearby.

Patrick (1956) was the first to distinguish the chaotic rocks of the mélange terrane from surrounding, coherently bedded strata. He separated a shaly conglomerate within his Black Shale Division of the Exploits Group. He also noticed that the mélange displayed more intense deformational features than surrounding rocks and suggested that it was "... in large part, a slump breccia...".

More recently, the investigations of Kay (1967, 1970, 1972), Williams (1967), Horne (1968, 1969) and Helwig (1969) have all helped to elucidate the nature of the Dunnage Mélange. These investigations focussed upon the region peripheral to Dunnage Island, the type area of the Dunnage Formation (Kay and Eldredge, 1968), with little regard for its southwest extension. Horne (1968) was the first to roughly outline its full extent to the southwest.

Within the restricted area of Dildo Run, interpretations of the structural-stratigraphic relations between the Dunnage and surrounding lithologies are controversial. Kay (1970) interpreted the Dunnage Mélange as one of many structural blocks bounded by transcurrent faults with significant lateral displacement. In contrast, Horne (1969) interpreted the Dunnage to be in conformable contact with overlying Caradocian shales.

The stratigraphy of the Exploits Group presents further problems. Williams (1963, 1964a, 1967) mapped the whole of the Botwood area in reconaissance fashion and correlated rock units throughout the regional area. He was the first to note discrepancies within Heyl's Exploits Series. New paleontological evidence, unavailable to Heyl, demonstrated that the Exploits Series was largely inverted and included ambiguous units (Williams, 1963). Thus, for example, volcanic rocks formed the base rather than the top of the sequence. Williams retained the term Exploits Group but left it undivided pending detailed work and re-vamping of Exploits stratigraphy.

Horne (1968) and Helwig (1967) studied areas immediately east and west of the Bay of Exploits, and their studies led to a correlation chart for Notre Dame Bay (Horne and Helwig, 1969).

Helwig (1969) redefined the Exploits Group in the New Bay area to the west of the Bay of Exploits, retaining only one unit from Heyl's original Exploits Series, the Lawrence Harbour Shale. Units included in the redefined Exploits Group, from oldest to youngest, are the Tea Arm, Saunders Cove, New Bay, Lawrence Head, Lawrence Harbour, and Point Leamington Formations, representing a sequence of basal volcanic rocks, medial argillites and an upper flysch unit. Heyl's term, the Sansom Formation is retained for easterly correlatives of the Point Leamington Formation.

On the southwestern part of New World Island, Horne (1968) followed Kay's (1967) subdivision of New World Island into three structural blocks, each characterized by a slightly different stratigraphy, i.e. the Dildo, Cobb's Arm and Toogood sequences.

More recently, Bergström, Riva and Kay (1975) subdivided the Cobb's Arm sequence into a southwest Virgin Village sequence and northeast sequence retaining the original name. Unfortunately, Lower and Middle Ordovician formational nomenclature does not extend outside a single block, though units are correlative. Thus a very fragmented stratigraphic framework has evolved for the New World Island area.

Present stratigraphic nomenclature in the Bay of Exploits is a hybrid between the Exploits Group (Helwig, 1969) and the Dildo Sequence (Kay, 1967; Horne, 1968) (fig. 4). Oversby (1967) extended Exploits Group nomenclature to Upper Black Island of the present study area, while Horne (1968) has extended the Dildo Sequence nomenclature southwestward to the smaller islands in the Bay of Exploits.

1-6 The present study

1-6.1 Scope and purpose

The present study is concerned with the extent, nature and boundary relationships of the southwest portion of the Dunnage Mélange. As previous work has been confined to the Dildo Run area, ideas concerning

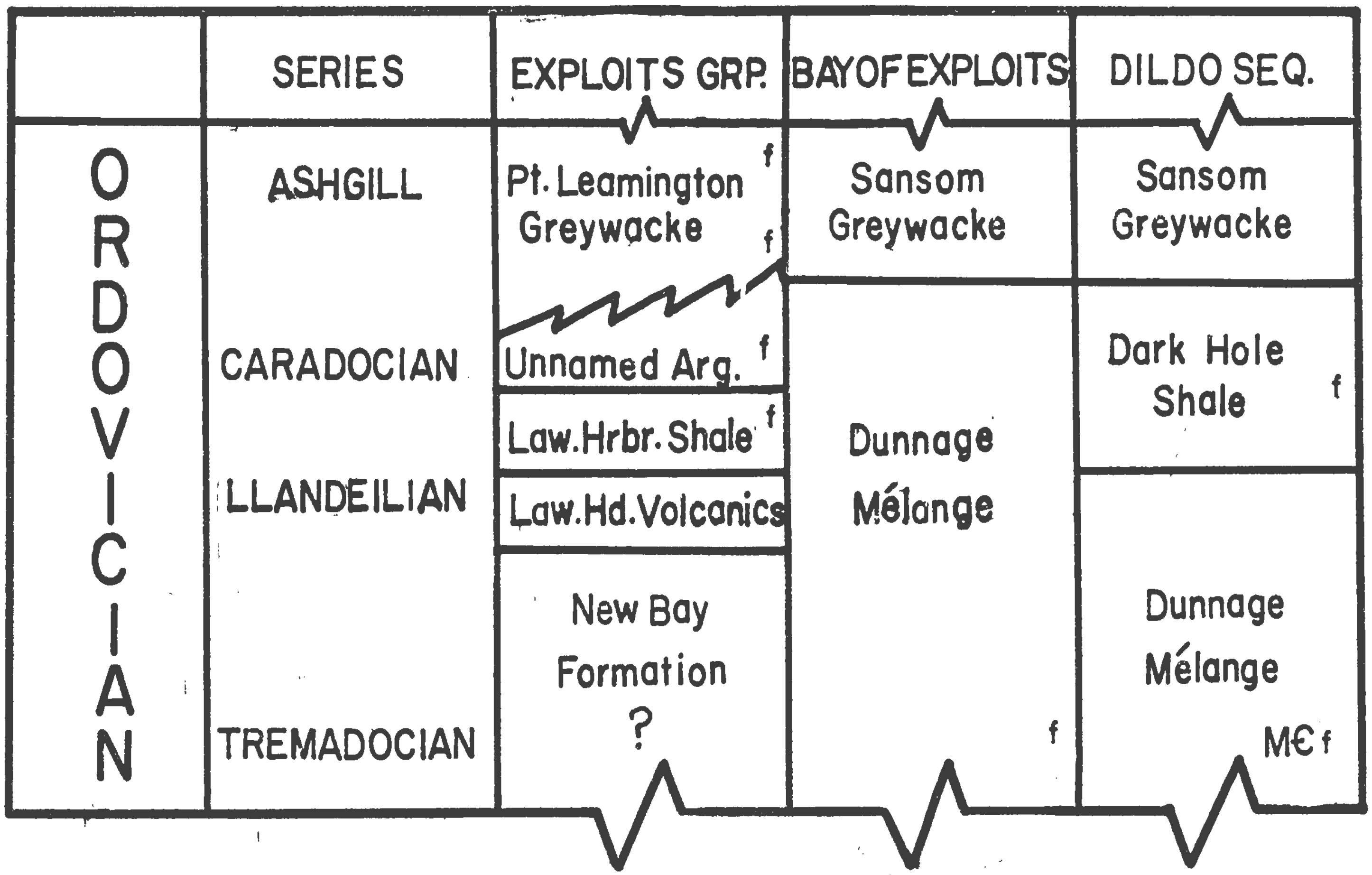


Figure 4: Stratigraphic correlation chart for the Bay of Exploits and bordering areas. (partially from Horne and Helwig, 1969)

the Dunnage Mélange there, and its regional relationshps and significance have been deadlocked. The purpose of working outside of the type area is three fold; (1) to delineate the southwest extent of the Dunnage Mélange, (2) to determine its relationships with surrounding formations, and (3) to determine the structure and constituent lithologies of the mélange terrane. The main body of this thesis is concerned with the resolution of these three points. The final section of this study reappraises the regional significance of the Dunnage Mélange in light of the new data.

1-6.2 Usage of the term mélange

Since the original geological use of the term mélange (Fr., mixture) by Greenly (1919), the word has had a vague definition. This study employs a descriptive usage, which is condensed from previous usages of the word. Mélange is a chaotic, heterogeneous assemblage of blocks (normally measured in meters) set in a fine-grained matrix. Larger blocks are of mappable dimensions. The term normally implies chaotic deposits in tectonically mobile areas.

Hsü (1968, 1974) and Cowan (1974) have defined the term as solely structural in connotation. Hsü compares and distinguishes tectonic mélange from sedimentary olistostrome, and Cowan equates mélanges with faults. Berkland et. al. (1972) and Wood (1974) have used broader definitions of the word, not particularly stressing tectonic aspects. Greenly (1919) intended no genetic inferences by using the term and most usages of the word are in a descriptive sense, thus there appears to be no logical reason to narrow the usage of the word to apply only to tectonic mixtures. If genesis need be implied, the adjectives tectonic or sedimentary can be added, though in many situations, such as the case of the Dunnage, sedimentary and tectonic processes are indistinguishable.

Confusion of terminology has also been introduced by geographically restricted names for local mélanges, such as the Alpine wildflysch, the argille scagliose of Italy, and the türlü güvec of Turkey (Ager, 1973). These terms should be used only in direct reference to a specific area.

1-6.3 Mapping methods

Mélanges represent unique terranes that do not comply with normal rules of stratal continuity and superposition (Hsu, 1968). In the present field area, the melange is considered as a single unit, while blocks large enough to be resolved at a 1:50,000 scale have been separated on the geological map (fig. 2). Most of the field mapping is based on excellent coastal exposure, augmented by a few inland traverses.

In many places, the boundaries of larger blocks are not exposed, though interpretation is aided by distinct topographic changes at the boundary between resistant blocks and easily eroded shale matrix.

The major measurable structural feature in these terranes is the pervasive foliation common to most, as bedding is usually obliterated. Particular care is necessary when measuring the orientation of the foliation in the vicinity of large resistant blocks, as foliation parallels their perimeters for short distances (50 m.) away from their boundaries.

ACKNOWLEDGEMENTS

I express my appreciation to Dr. Harold Williams for suggestions, supervision and support of all aspects of this project including the general fiddling around involved. This study was supported by N.R.C. grant A5548 and in later phases by E.M.R. Research Agreement No. 1135-D13-4-94/75. I extend my gratitude to Drs. A.R. Berger, W.D. Brückner, L. Fahraeus, M.J. Kennedy, D.F. Strong and Dr. R.K. Stevens and my fellow cohorts, Paul Dean, Sean O'Brien and Sandro Serra for general discussion and field consultation. Acknowledged for their technical assistance are Foster Thornhill, Gerry Ford and Lloyd Warford, Gertrude Andrews, David Press and Wilfred Marsh. Special thanks are extended to Phyllis Stratton for typing.

I would like to express warm appreciation to Mrs. Fred Small of Lewisporte for her gracious hospitality and the use of her summer cottage and to Masters Barry Wells and Wayne LeDrew of Masons Cove for their frequent and pleasurable company.

II. GENERAL CHARACTERISTICS OF THE DUNNAGE MÉLANGE

The Dunnage Formation was first defined by Kay and Eldredge (1968). In recent years, the term Dunnage Mélange (Horne, 1969; Kay 1972) has been commonly used and will be employed throughout this study. The mélange is typified by slumped blocks of clastic sediment, limestone, mafic volcanic rock and gabbro enclosed in a dark scaley shale matrix. The size of the blocks varies dramatically, ranging from sandstone grains and pebbles to massive olistoliths hundreds of meters wide. Both blocks and matrix exhibit subtle changes along strike such that their character in the southwest is quite distinct from that of the northeast occurrences. In an attempt at clarity in presentation, this chapter gives an overview of all the pertinent data amassed for the Dunnage as a whole. Chapters which follow deal with the nature of the southwest portion of the mélange and refer back to information in this chapter where applicable.

2-1 Distribution

The Dunnage Mélange has been traced southwestward from its type area in Dildo Run, across the Comfort Cove Peninsula to its terminus at Stanhope (fig. 5). Thus it extends for 40 km along strike, with a maximum outcrop width of approximately 13 km. The true thickness of the Dunnage is impossible to determine because of its internal chaos, though Horne (1968) has conjectured that it is on the magnitude of a few thousands of meters. Likewise, possible structural imbrication within the mélange is difficult to prove or disprove, though this is suggested by prominent lineations and the possible obliteration of a complex fault system that projects from New World Island southwestward

Figure 6: Distribution of Ordovician intrusive rocks in the Dunnage Mélange and surrounding areas

into the chaotic terrane (Horne, 1968).

Where layered rocks occur in the mélange, bedding is consistently steeply-dipping and usually north facing, similar to the disposition of strata in surrounding units. In its most southwesterly extreme, the Dunnage Mélange forms the core of a gently plunging syncline, which has an axial trace oriented to the northwest. This structure is believed to be the compliment of a major anticline situated to the west on the Fortune Harbour Peninsula (P. Dean, pers. comm., 1976).

Structurally, the Dunnage is confined to the southeast by the Reach Fault, and to the northwest by a complex of faults that includes the Dildo Fault. Locally, where the contact has not been obliterated by later intrusions, the mélange is in conformable, transitional contact with surrounding lithologies.

2-2 Salient features

The most striking feature of the Dunnage Mélange, although chaotic, is that all of the included blocks, with very rare exceptions, are indigenous to the local geology. In places, they can be matched to an original stratigraphy.

To the southwest, the mélange overlies and interdigitates with the gabbro-infested Ordovician New Bay Formation of the Exploits Group (Helwig, 1969). The predominance of gabbro blocks within the Dunnage Mélange is confined to the area proximal to this contact zone. Similarly, in the northwest portion of the mélange, from Embree to Cheneyville, the largest mafic volcanic blocks define a wide zone which projects westward into volcanics of the Lawrence Head Formation, also of the Exploits Group.

Along its northwest side on New World Island, the mélange is bordered by north-facing black shales of the Caradocian Dark Hole Formation (Horne, 1968). The nature of this contact is controversial. Kay (1972) interpreted it as a fault separating distinct sequences. Horne (1969) interpreted the same contact as locally conformable. The continuity and attitude of the Dark Hole Formation, and the gradational nature of some of the contacts, are all very suggestive of a depositional contact between the mélange and north-facing shales. Also, in contradiction to Kay's idea, all major faults on New World Island have north-facing Silurian strata to the south and older Ordovician rocks to the north. In the vicinity of the Dunnage-Dark Hole contact, the Dildo Fault (Kay, 1970) does not display this structural relationship, as the mélange to the south is interpreted as older than Dark Hole shales to the north; a conclusion based in part on stratigraphy to the southwest. Also, porphyry cobbles in the Dark Hole Formation at Cheneyville bear striking resemblance to the Coaker Porphyry (Kay, 1972), an intrusion confined to the mélange terrane, further implying a depositional contact between the Dark Hole and the Dunnage. In addition, the Lawrence Head Formation, interpreted as a correlative of the largest volcanic blocks throughout the northwest portion of the mélange, is overlain by the same Caradocian black shales. Thus an important structural dislocation at the Dunnage-Dark Hole contact appears inconsistent with stratigraphic relations and the structural style of New World Island.

The matrix of the mélange exhibits subtle changes along strike. To the southwest, the matrix shale is grey and in many places contains thin, buff siltstone interbeds that are attenuated and severely disrupted. This structural disarray is similar in style to that of thin beds of the New Bay Formation on Upper Black Island. To the northeast, the matrix of the mélange is smeared, black and green shale.

The above relations strongly imply that the Dunnage Mélange is an easterly, possibly distal, chaotic equivalent to part of the Exploits Group, and consequently is pre-Caradocian in age.

A suite of intrusions, which range from quartzo-feldspathic porphyries in the northeast to more gabbroic phases in the southwest, is unique to the Dunnage terrane. The commonest of these is the Coaker Porphyry (Kay, 1972), which comprises approximately one-third of the outcrops in the northeast portion of the mélange terrane. It intrudes the mélange and is itself cut by the Loon Bay granodiorite. Less common intrusions include the Causeway Diorite and the Puncheon Syenite (Kay, 1972) in the northeast, and the biotite-rich Grapnel Gabbro (new) centrally located in the mélange. Biotite from the Causeway Diorite has yielded K/Ar ages of 428 $\pm$ 13 m.y. and 435 $\pm$ 13 m.y., and a Rb/Sr age of 454 or 480 m.y., depending upon the decay constant employed in age calculations (reviewed in Williams and Hibbard, 1976). The Causeway Diorite everywhere contains numerous inclusions of gabbro and ultramafic rock. Similarly, the widespread Coaker Porphyry locally exhibits the same texture, inferring a similar origin and age for these two intrusions. Based on isotopic ages and restriction of these intrusions to the Dunnage terrane, it appears that intrusion was coeval with mélange formation. Intimate relations between felsic dikes of unknown affinity and the mélange matrix also suggests igneous intrusion into soft sediments.

In addition to stratigraphic and intrusive relationships, paleontological evidence places loose constraints on the age of the Dunnage Mélange. Two fossil localities have been reported from the mélange, one on the shore of St. John's Bay, north of Stanhope (Williams, 1967), and the other on Dunnage Island (Kay and Eldredge, 1968).

Near Stanhope, dendroid graptolites, presumably from the black shale matrix of the mélange, are identified as Dictyonema sp.. This suggests a Tremadocian age, as all other dendroid graptolites reported in Newfoundland are of that age.

Fossils from the south coast of Dunnage Island are trilobite fragments contained in a limestone bed within a block of mafic volcanic rock. These are identified as Kootenia sp. and Bailiella sp. (Kay and Eldredge, 1968), and indicate a Middle Cambrian age for the limestone and volcanic block.

Thus the oldest known rocks in the Dunnage are Middle Cambrian, its matrix is locally Tremadocian, and uppermost parts are probably Caradocian.

The present study is mostly concerned with the structural and stratigraphic relationships of the southwest portion of the Dunnage Mélange, though its age and relationships with intrusions are important facets to be considered in the regional synthesis.

III. GENERAL GEOLOGY OF THE SOUTHWEST PORTION OF THE DUNNAGE MÉLANGE

3-1 Character of the mélange

The most distinctive feature of the Dunnage Mélange is the variety of lithologies incorporated as blocks in a grossly uniform matrix of black, green and grey shale. The largest olistoliths, measuring hundreds of meters across, are composed of basic volcanics, greywacke, or gabbro. The volcanic rocks and gabbro are confined to distinct zones; the volcanics occur across the northwest portion of the mélange and the gabbro is localized toward the southwest. Smaller inclusions are dominantly granule - to cobble-sized quartz and lithic fragments that are randomly dispersed throughout the mélange. Most blocks are indigenous to the area and represent either formations once interbedded with the matrix or lithologies of local provenance. Exotic inclusions, or blocks of unknown origin, are very rare. The mélange matrix is a smeared, slickensided, pyrite-rich shale that ranges in color from black and black and green in the northeast, to black and grey in the southwest portion of the mélange.

The whole of the mélange portrays internal chaos, as the concentration of inclusions in the matrix is random, and both the form of the blocks and the character of the matrix are highly variable.

3-2 Matrix and inclusions

A ubiquitous, scaley black and grey shale forms the matrix to the southwest portion of the Dunnage Mélange. This contains abundant tuff, with quartz, ghost feldspars, and chlorite also revealed in thin section. Locally, north of Lewisporte and also west of Comfort Cove, black and green matrix shales have been mixed by flowage and they are similar to matrix shales in northeast occurrences at Dildo Run (pl. 1). The mélange matrix is typically structureless, with the exception of a steeply dipping cleavage. The intensity of the cleavage is proportional to the number and size of inclusions in the matrix. Thus, where clasts abound, or are large, the shale is intensely cleaved and fissile; in areas where inclusions are sparse or small, the matrix has a more massive aspect.

The shale matrix is the unifying lithology of the mélange terrane, as it envelops and forms the link between many diverse inclusions. Sedimentary inclusions, which dominate olistolith types in the mélange, range in form from vague zones and poorly delineated rafts, to sharply defined resistant blocks, to extensive bedded sections of uncertain form. Igneous inclusions are mainly well defined, equidimensional blocks. In most places, the mélange matrix penetrates sedimentary and volcanic inclusions in irregular, intricate patterns, both microscopically and macroscopically (plts. 2, 3).

3-2.1 Zones of sedimentary inclusions

The mélange is rarely void of inclusions over large areas. Where blocks of mappable scale are absent, zones of smaller sedimentary inclusions are intimately mixed with the black and grey matrix shales. These distinct areas, which can be only vaguely delineated, include zones of thin attenuated siltstone bands, pebbly mudstone zones, and conglomeratic argillite.

Locally, as exposed along the eastern shore of the Lewisporte Peninsula, the matrix contains thin (approximately 2 cm.), buff-colored, quartz-rich siltstone to fine grained sandstone beds that are attenuated

Plate 1: Smeared black and green matrix shales on Comfort Cove Peninsula. This lithology is common in the northeastern section of the mélange, but confined to local areas in the southwest portion

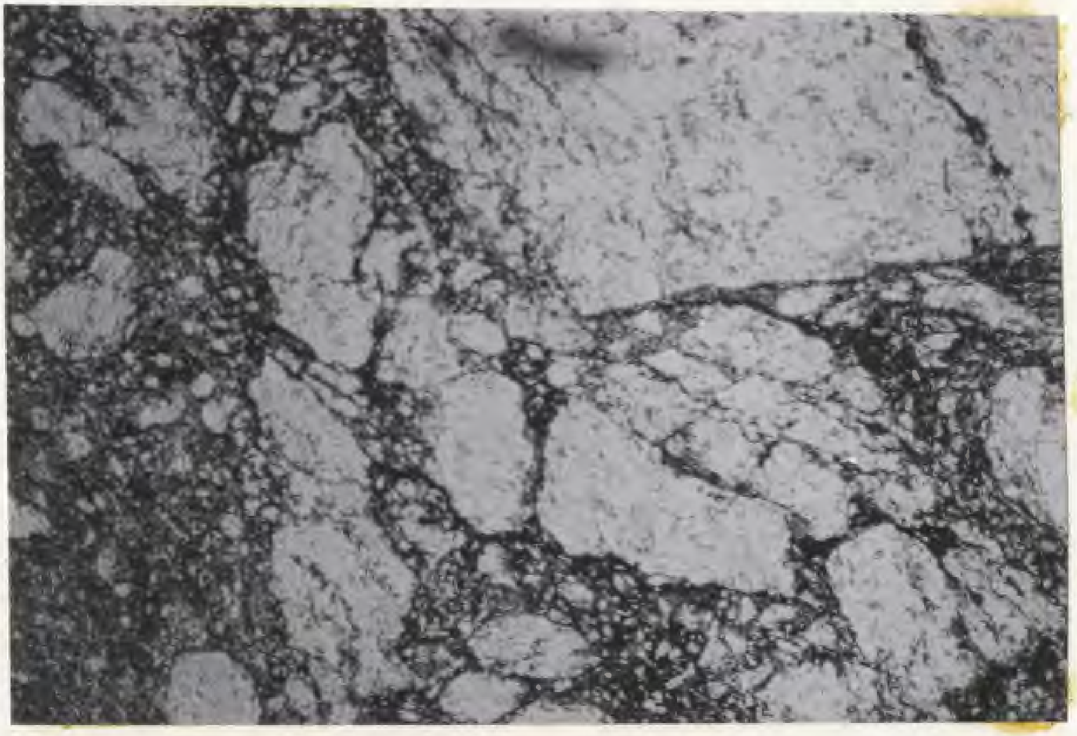


Plate 2: Microscopic view of matrix shale penetrating the margin of a quartz rich greywacke (X10, uncrossed nicols)

Plate 3: Typical wispy, network penetration of the mélange matrix into a grewyacke block

and disrupted (pl. 4). This feature is descriptively termed toothpaste structure, as its chaotic appearance resembles ptygmatic folding or flowage of viscous material. It is ubiquitous in the southwest portion of the mélange, where it usually occurs as zones in a massive argillite matrix. The appearance of these beds is reminiscent of continuous, slump folded siltstone bands interbedded with massive mudstone in the New Bay Formation on southeast Upper Black Island. This suggests that the New Bay Formation may be a possible source area for part of the mélange matrix.

Pebbly mudstone zones occur at the base of the Dunnage, north of Stanhope Cove, north of Lewisporte, and east of Michael's Harbour. These are marked by a massive mudstone matrix containing angular to rounded fragments of greywacke, siltstone, argillite, chert, carbonate and minor amounts of volcanic debris (pl. 5). The restricted occurrence of pebbly mudstones and their similarity with strata in the New Bay formation, to the south and west, implies a similar provenance for these units in both formations.

Conglomeratic and bouldery argillite zones are widespread throughout the mélange and are well exposed at Foulke Cove and Northwest Bottom (pl. 6). This mixture of matrix and clasts that range in size from granules to boulders a few meters in diameter, mimics, on a larger scale, the dispersed aspect of the disrupted siltstone bands. The mélange matrix in conglomeratic argillite zones is extremely fissile, bestowing a rubbly aspect to the outcrops where blocks are weathered out. Most clasts are surprisingly well rounded, and are dominantly composed of extremely obdurate, quartz-rich greywacke and mudstones, with a subordinate number of carbonate and volcanic cobbles. In thin

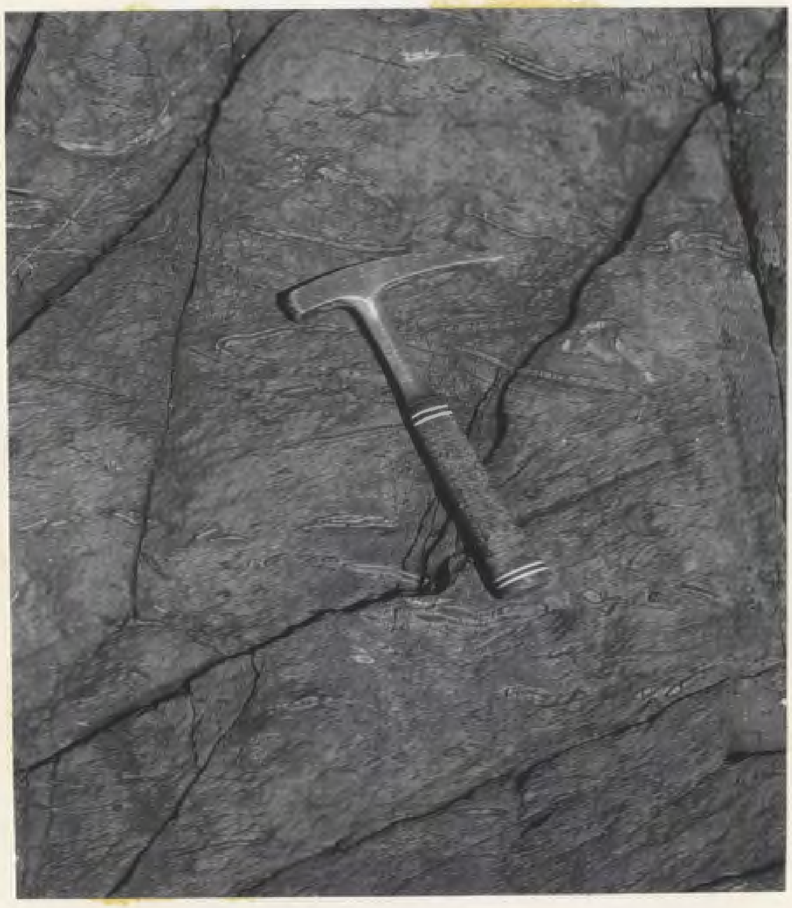


Plate 4: Attenuated and disrupted siltstone bands, informally termed toothpaste structure. This feature is common to the matrix of the southwest portion of the Dunnage Mélange.

Plate 5: Pebbly mudstone at the base of the Dunnage, just north of Stanhope Cove. Primary constituents are greywacke, siltstone, limestone, volcanic fragments and abundant pyrite

Plate 6: Rubbly conglomeratic argillite unit forms an intertidal terrace in Southwest Bottom . . . .

section, the greywacke is typically composed of quartz and plagioclase grains with lesser amounts of lithic fragments set in a tuffaceous and argillaceous matrix. This lithology is similar to greywacke occurring to the immediate west, in the New Bay Formation and to clastics in the lower parts of the Summerford Group (Horne, 1968), to the northeast. This suggests a similar source terrane for all these rocks.

Sedimentary zones encompass a large part of the mélange, where they are intermediate in scale between barren matrix and large olistoliths. In the field, map scale olistoliths usually occur in proximity to the sedimentary zones, thus amplify the irregular mosaic pattern of the mélange.

3-2.2 Sedimentary blocks

Large, resistant, clastic sedimentary blocks and disrupted lentils, such as those displayed on the west coast of the Lewisporte Peninsula, are resolvable for geological mapping at a scale of 1:50,000. The composition of isolated clastic blocks ranges from greywacke to mudstone, to laminated siltstone and tuff, to argillite. Massive, well defined lentils, contorted and disrupted in the mélange matrix are dominantly composed of the same quartz-rich greywacke and mudstone as occurs in conglomeratic argillite boulders, suggesting a similar source for both features. The planar form of many greywacke blocks and lentils infers that they are disrupted strata that were once interbedded with the mélange matrix.

Laminated, light and dark siltstone and tuff blocks occur on the Masons Cove Peninsula and on Sivier Island. Their tabular form and ragged boundaries that interfinger with the matrix suggests that they, too, were once interbedded with the mélange shales. Argillite rafts display this same boundary relationship, inferring blocks of matrix within the matrix.

Carbonate blocks are common within the Dunnage, though normally they are small and inconspicuously disposed in conglomeratic argillites. Exceptional occurrences of large (5-20 m diameter), rounded carbonate blocks occur on the east side of Camel Island. All carbonate occurrences are associated with basic volcanics. This is similar to that of the Cobbs Arm limestone that parallels the Dunnage in an outcrop belt to the northwest at New World Island. The proximity of the Cobbs Arm to the Dunnage hints at a northerly provenance for some of the Dunnage carbonate blocks. Other carbonate blocks are Middle Cambrian and obviously older than the limestones at Cobbs Arm (Kay and Eldredge, 1968).

Internally, all types of blocks and lentils may display continuous beds (pl. 7), chaotic bedding and brecciation, or are massive. Chaotic bedding and brecciation are common within all blocks but are best developed in argillite rafts, laminated siltstone - tuff blocks, greywacke lentils and carbonate blocks.

Large (10 m diameter) rafts of black argillite, as exposed on the west coast of the Comfort Cove Peninsula, are internally chaotic, closely resembling conglomeratic argillite. Here, tuffaceous sandstone blocks that are round to loaf-shaped are strewn chaotically in a cleaved black shale matrix. The blocks are discernable from the surrounding, fissile, mélange matrix only because of the intensity of cleavage, which is more intense in the mélange matrix, and because the cleavages in blocks and matrix are locally at oblique angles.

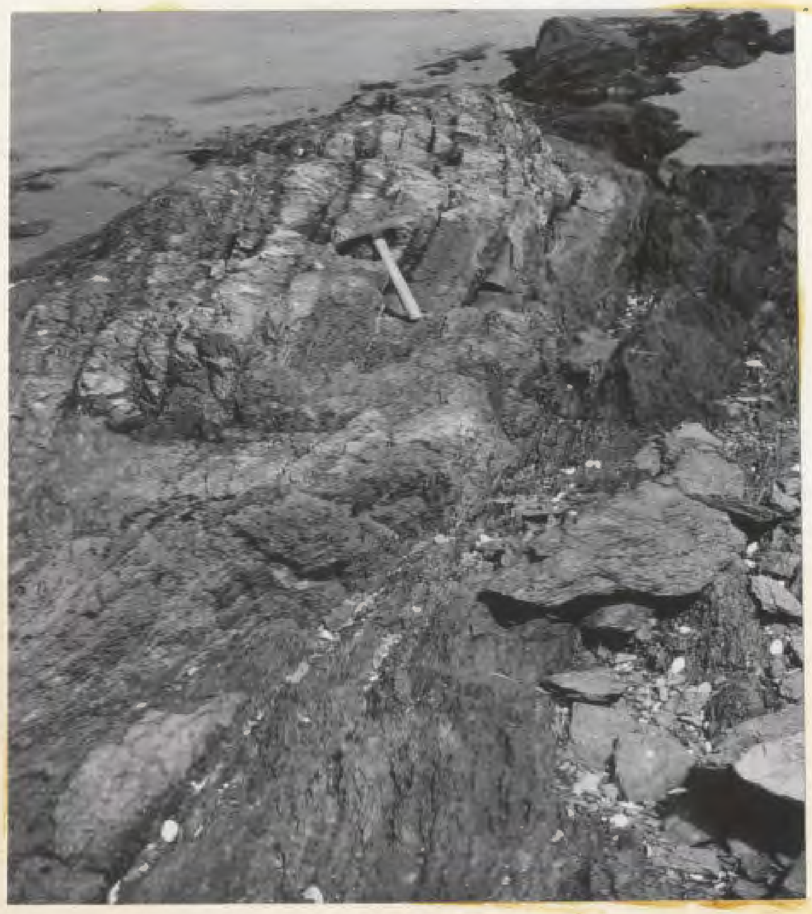


Plate 7: Block of medium bedded greywacke in which bedding faces north, i.e. to the left of the photo. Note attenuation of the block and intense cleavage in the surrounding matrix

Locally, greywacke blocks, such as those exposed at Comfort Cove and on eastern Camel Island, are internally brecciated (pl. 8). Greywacke clasts within these intrablock breccias are angular, usually display bedding, and float randomly in a massive greywacke-mudstone matrix. Some of the clasts are traversly cut by small quartz veinlets that terminate abruptly at the clast boundary. These veins occur in association with angular quartz inclusions (pl. 8). The quartz inclusions are also common constituents of chaotically slump folded siltstone-tuff blocks.

Bedding or primary structures within carbonate blocks have been thoroughly obliterated by total internal brecciation. All carbonate blocks in the area have this shattered aspect, which is plainly evident on the weathered surfaces of these blocks (pl. 9). The carbonate matrix of these breccias forms a scant network around numerous micrite clasts.

The internal features of diverse sedimentary blocks have no uniform pattern, thus mimicking the chaos of the regional mélange terrane on a smaller scale.

3-2.3 Intact bedded sections

Intact sections exposed on Camel Island and Crow Island displays a continuous volcanic-sedimentary succession. On northeastern Camel Island, a sequence of grey shale, manganiferous silty sandstone, cherty argillite and limestone are relatively undisturbed compared to the melange on the southern part of the island.

The manganiferous portion of the section contains manganese rich silty sandstone, laminated manganiferous argillites and siltstones,

Plate 8: Greywacke lentil displaying intrablock brecciation, with clasts of thin bedded siltstone and angular, pure quartz pebbles, Comfort Head, Comfort Cove Peninsula

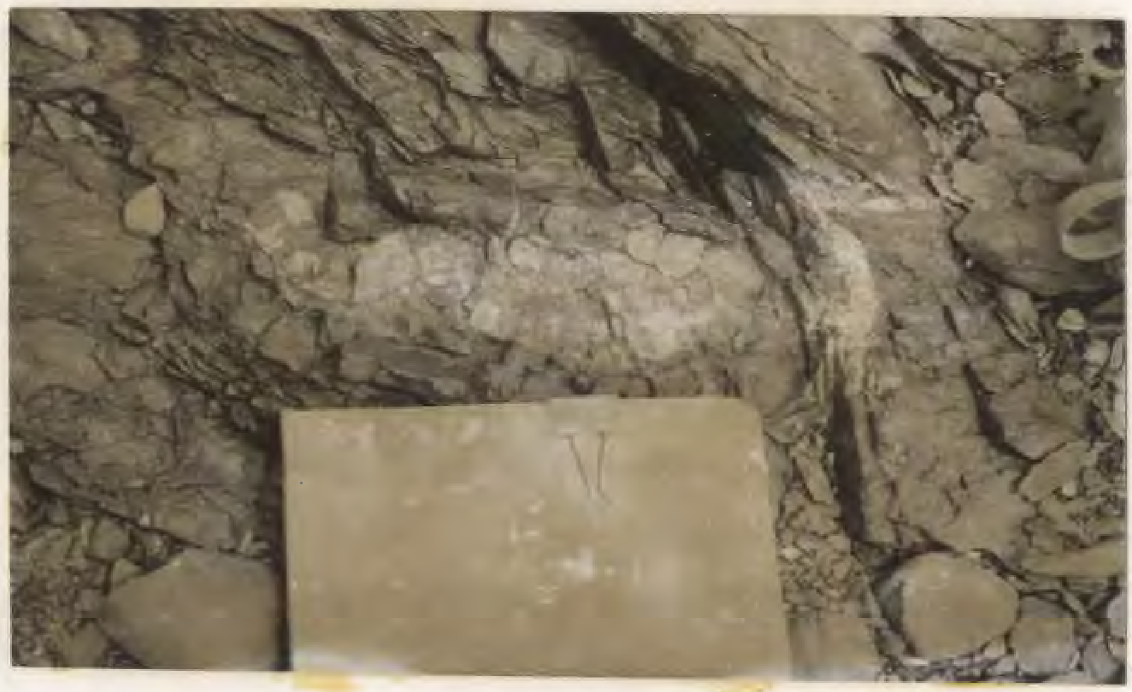


Plate 9: Carbonate block displaying brecciation common to all carbonates within the mélange: Foulke Cove

and manganese bearing pellets in grey shale (plts. 10, 11). These nodules may represent sedimentary concretions or structurally detached and rolled bedding remnants. Locally, the manganese pellets contain visible bits of copper in their cores, but chemical analyses indicate only minor amounts of copper (Appendix I). This section is overlain by argillite, basic tuff and agglomerate, broken pillow breccia, and pillow lava. The whole sequence is steeply southeast-dipping to vertical, facing northwest and striking northeasterly toward Crow Island.

Strata on Crow Island are more coherently bedded and consist of reworked pyroclastics and tuffs, agglomerate, chert and porcellanite. Layers range from finely laminated tuff, to medium bedded Bouma sequences of reworked tuff (pl. 12) to massive agglomerates and tuff flows up to ten feet thick. These sequences represent the largest sedimentary inclusion in the southwest portion of the Dunnage. No gradational sizes exist between typical sedimentary blocks and the large Camel-Crow Island block, suggesting an alternate mode of incorporation into the mélange for the latter compared to that of the smaller blocks.

3-2.4 Volcanic blocks

Basic volcanics compose the largest blocks in the Dunnage mélange, and define a wide zone across its northwest part (fig. 5). In the field area, the blocks can be traced from Masons Cove, across Sivier Island, to Comfort Cove (fig. 2).

The volcanic blocks are basic pillow lavas, flows and associated pyroclastic rocks. These occur as lentils or as large, equidimensional

Plate 10 & 11: Cross sectional view and plan view of manganese-rich pellets of unknown origin. They are internally zoned and commonly subparallel to cleavage. North Camel Island.

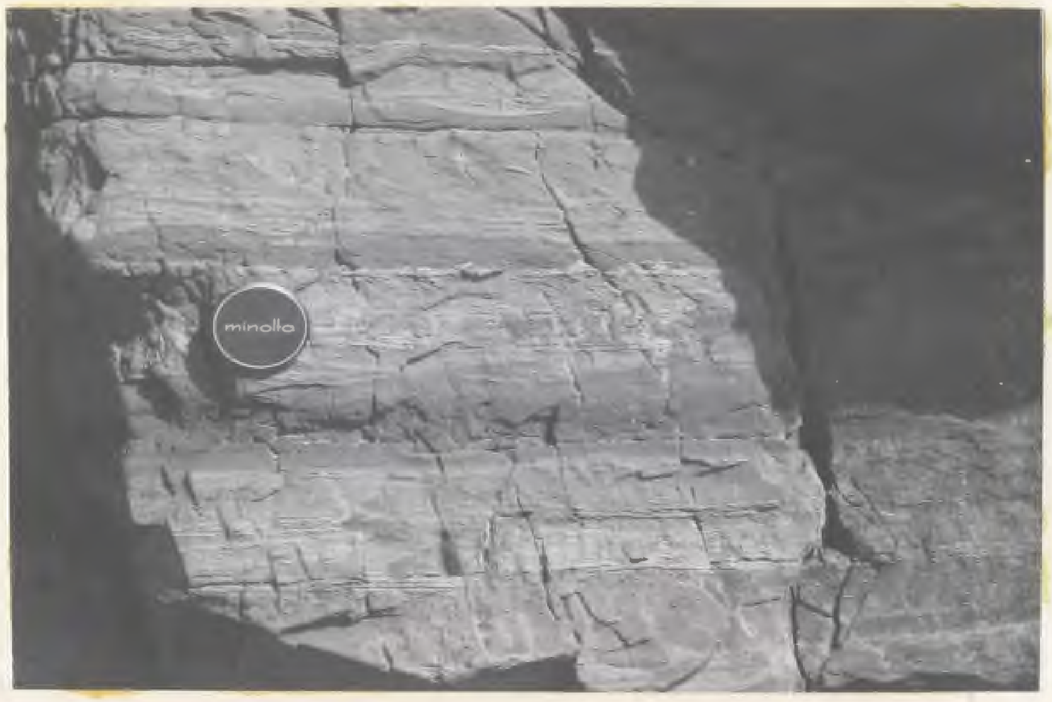


Plate 12: Well bedded tuffaceous greywacke and mudstone exhibiting Bouma sequences. Crow Island

Plate 13: Graded, basic volcanic agglomerate, Northwest Bottom

blocks, hundreds of meters in diameter. One disrupted, spherulitic rhyolite layer (approximately 1 m wide) has been traced for a kilometer along the Masons Cove Peninsula.

Locally, lava flows are interbedded and intimately entwined with the mélange matrix, as on the southeast coast of Camel Island. Basal parts of these flows locally contain rip up slabs of shale. On the southeast coast of Sivier Island, ropey lava, along with a wide assortment of basic pyroclastic rocks, occurs in a large knocker. Lava occurring in blocks at the southern end of Foulke Cove and locally in Northwest Bottom, is very scoriaceous, resembling a basic pumice, thus suggesting original deposition in very shallow water, or subaerially.

The most common pyroclastics associated with basic flows and pillow lava are monolithologic agglomerates that occur commonly with graded and subrounded clasts with little matrix (pl. 13), angular bombs with chill margins in a tuffaceous matrix (pl. 14), or with splash bombs in tuff and lapillistone.

The most spectacular pillow lavas, as well as basic volcanics in general, are exposed on Camel Island and on the Comfort Cove Peninsula (pl 15). At the latter locality, volcanic blocks over a kilometer wide, protrude from the sea to form dramatic cliffs. Patches of black shale pasted on these cliffs indicate that the volcanics are blocks in the mélange (pl. 16). Large undeformed, amoeboid pillows are characteristic of some large volcanic blocks on the Comfort Cove Peninsula. Locally, interstices between these pillows are filled with either a distinct blue-green chert or carbonate (pl. 17). On Camel Island, a well exposed broken pillow breccia (Carlisle, 1963) that interfingers with agglomerate is associated with pillow lava. The

Plate 14: Agglomerate, west of Masons Cove, containing clasts with margins chilled against the tuffaceous matrix

Plate 15: Well formed basic pillow lava on the west side of Comfort Cove Peninsula. Largest pillow approximately 1 m across

Plate 16: Leviathan basic volcanic block in mélange west of Comfort Cove, note author at lower right for scale. Dark staining on central part of the block is the mélange matrix pasted on the knocker

Plate 17: Intermingling of carbonate and basic pillow lavas, approximately 200 m north of Foulke Cove. Limestone, with similar association, has yielded Middle Cambrian fossils on Dunnage Island

amoeboid pillows, blue-green chert fillings, and associated pyroclastic rocks occurring in these blocks are characteristic features of the Lawrence Head Formation, to the west of the Bay of Exploits. The Lawrence Head Volcanics or correlatives are thus a likely source for the large volcanic blocks in the Dunnage.

A remnant piece of bedded black and green argillite that is attached to one volcanic block at Comfort Cove, can be traced into smeared black and green melange matrix shales. This relationship implies that part of the melange matrix may also be correlative with the Lawrence Head Formation.

3-2.5 Gabbro blocks

Gabbro blocks are generally confined to the southwest portion of Dunnage, where they form a distinct zone toward the base of the mélange. Their distribution in linear zones suggests that they are disrupted sills and dikes (fig. 2).

In the field, gabbro blocks in the mélange are usually well exposed and form knobs and hills (pl. 18). Smaller blocks locally display narrow chill margins that probably formed before their incorporation into the Dunnage. The tapered, elongate shape of some of these blocks supports the idea that the gabbro was crystallized at the time of incorporation into the mélange. Larger gabbro rafts are inferred from limited outcrop and prominent ridges observed on aerial photographs. Contact relations of the larger blocks are rarely exposed.

The gabbro is of variable texture and ranges from fine to medium grained. The most common textures are hypidiomorphic/equigranular to subophitic and porphyritic with plagioclase glomerophenocrysts up to 15 mm. The latter plagioclase crystals give a distinct spotted aspect to the gabbro.

Plate 18: Small gabbro block in Southwest Bottom of Little Burnt Bay. This is one of the few gabbro blocks not confined to the basal part of the mélange

Plate 19: Thin to medium bedded New Bay tuffaceous mudstones intruded by prominent gabbro sill at Emily Cove.

Gabbro dikes and sills, similar in lithology to some gabbro blocks in the Dunnage, pervasively intrude the New Bay Formation to the west of the mélange. Most gabbro blocks in the Dunnage are, therefore, most likely derived from gabbro sills in the New Bay, thus establishing an important link between the Dunnage and the New Bay Formation.

The gabbro may be genetically related to intrusions that occur in the northeast portion of the Dunnage (fig. 6). The biotite rich Grapnel Gabbro (new), the Puncheon Syenite, the Coaker Porphyry, and its more xenolithic phase, the Causeway Diorite (Kay, 1972) occur as dikes, sills, and stocks unique to the northeast portion of the mélange. The Causeway has yielded K/Ar ages of 428 ± 13 m.y. and 435 ± 13 m.y. and Rb/Sr ages of 454 m.y. or 480 m.y. depending upon the decay constant used in calculation of the age (Kay, 1974). The dates suggest that the intrusions were coeval with deposition of mélange lithologies and possibly with incorporation of the gabbro blocks in the southwest portion (see Chap. 2).

3-3 Relationships of the Dunnage Mélange with surrounding rocks

The southwest portion of the Dunnage Mélange is surrounded by strata of the Exploits Group and it is cut by granodiorite intrusions. To the south and west, near Upper Black Island, Thwart Island, and at Michael's Harbour, the New Bay Formation borders the Dunnage Mélange. The Lawrence Head Formation borders the mélange to the northwest, on Upper Black Island. Locally, at Knight's Island, the Dunnage is bounded by the Sansom Greywacke. The Long Island and Loon Bay batholiths truncate the mélange in the central Bay of Exploits and on the Comfort Cove Peninsula, respectively. The contacts of the Dunnage with these

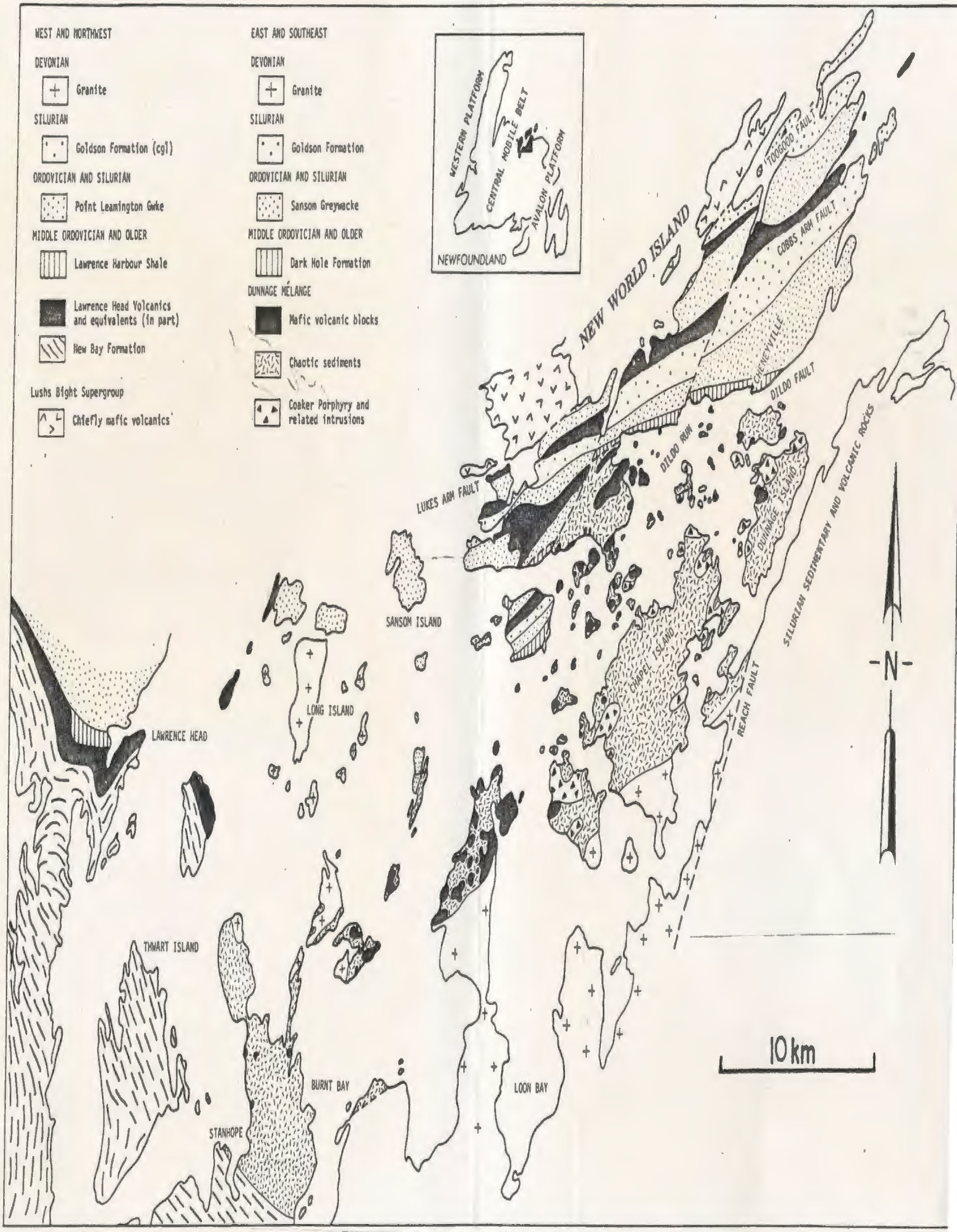


Figure 5: General geology of the Dunnage Mélange and surrounding area (from Williams and Hibbard, 1976)

units are very limited in exposure; some are beneath the waters of the Bay of Exploits and inland contacts are covered by dense vegetation.

3-3.1 The New Bay Formation and its relations to the Dunnage Mélange

The New Bay Formation of the Exploits Group (Helwig, 1969) is a clastic sequence of thick bedded, buff colored, pebbly turbidites with thin bedded grey to black mudstones. In places, pervasive gabbro sills form up to 80% of the Formation (fig. 2). The coarse sandstone turbidites, well exposed on Thwart Island, are generally in beds from several centimeters to a meter thick. Their weathered surfaces commonly display prominent feldspar crystals in addition to the usual quartz grains and lithic fragments. Locally, the turbidites are interbedded with argillite, mudstone and conglomerate. Conglomerates are polymictic with a predominance of limestone, shale, rip-up sandstone, chert and porphyritic rhyolite clasts. Locally, conglomerates are transitional with pebbly mudstones.

Previously unclassified strata on Cat Island and at Michael's Harbour are included here, in the New Bay Formation. These consist of striking assemblages of turbidites, ranging from normal sandstone-argillite alternations with finely laminated siltstone and massive conglomerate interbeds to mudstones with pebbly influxes and mudflake conglomerates to massive tuff flows. Sedimentary structures that abound in these beds include lamination, cross beds, ripple drift lamination, flasure bedding, convolute lamination, load casts, pseudonodules, rip-up structures and abundant slump structures. Sills of gabbro are common among these sediments. The position and lithologic similarity of these beds to New Bay strata suggest correlation and all are included in the New Bay Formation.

Evidence of local volcanic activity is common in the upper parts of the New Bay Formation. It is represented by dacitic to andesitic flows, agglomerates and highly tuffaceous sediments. Dacite flows are typically massive, vesicular and porphyritic and contain quartz spherules, while porphyritic andesite flows are distinctly reddish brown to purple. In thin section, these are altered, with an abundance of sericitized plagioclase and chlorite.

The agglomerates are locally spectacular, with fragments ranging upwards to a meter long. The most common constituents are fragments of tuff, dacite, purple porphyritic andesite, green chert and jasper. Commonly, these volcanics are associated with finely laminated buff and olive tuffs and graded tuffaceous sandstone, which are locally pierced by acidic diatremes and ubiquitous gabbro sills (pl. 19). Spatial distribution of the gabbro sills in the New Bay strongly suggests that they were feeders to the immediately overlying Lawrence Head Volcanics.

The relationship between the New Bay Formation and the Dunnage Mélange can be gleaned from exposures at James Island, near Stanhope Cove, Freake and Mussel Island in Burnt Bay, and at Michael's Harbour.

Near James Island, steeply dipping New Bay strata of Thwart Island strike southeasterly and face northeastwards toward the beds of James Island. The stratigraphic succession on James Island consists of a basal tuffaceous sandstone, of typical New Bay lithology, overlain by a basic volcanic flow rock and associated limestone, with a capping of pebbly mudstone. The basal tuffaceous sandstone is massive, intensely cleaved, and contains attenuated thin beds resembling the familiar disrupted siltstone bands of the Dunnage, elsewhere. It also contains many hooked rip-up slabs of typical New Bay sandstone, rounded pebbles and blocks of quartzite, and local chert nodules. Most of these features indicate an unstable environment of deposition for the sandstone.

The basic flow rock above the sandstone appears to be a slide lentil of limited extent.

Overlying pebbly mudstones have disrupted beds that contains dominantly rounded chert and rhyolite porphyry pebbles (pl. 20) thus indicating a continuing unstable depositional site. Across a narrow water gap, the Dunnage is the nearest unit immediately to the east. The disordered nature of this section and its position between the New Bay Formation and the Dunnage Mélange indicate that it is transitional between these units. Structural dislocation of this section may be present underwater, but the striking similarities between the James Island lithologies with both those of the New Bay Formation and Dunnage Mélange implies a stratigraphic transition.

Southeast, on the Stanhope Peninsula, New Bay strata swing gently to the east. Near Stanhope, a gabbro sill separates agglomerate, pebbly mudstone, and semi-massive, grey New Bay argillites to the south from highly cleaved black argillite of the Dunnage to the north. The cleaved argillites are characterized by stringers of buff, tuffaceous siltstone, chert nodules, rhyolitic porphyry clasts and blocks of black siltstone that are suspended with their long axes parallel to the cleavage. A short distance eastward along strike and across Stanhope Cove, basic pillow lava, pillow breccia and agglomerate are bordered by

Plate 20: Wispy, flow bedded pebbly mudstone in transition zone between the New Bay Formation and the Dunnage Melange at James Island. Note rhyolitic porphyry and chert fragments. Matrix is chlorite rich

grey shales and massive pebbly mudstones north along the coast. The pebbly mudstones contain clasts of buff tuffaceous sandstone, typical of New Bay turbidites, porphyritic rhyolite, angular quartz, green chert, volcanic fragments, siltstone, argillite, limestone, and abundant authigenic pyrite. Typical mélange terrane occurs north along the coast. This sequence represents a transition from bedded New Bay agglomerates, pebbly mudstone, and shale into intensly cleaved shale with blocks, the Dunnage Mélange.

Lithologies on Mussel Island, Burnt Bay, are transitional in position and character between the Dunnage and the New Bay Formation. Volcanics and sediments of the New Bay Formation outcrop on Freake Island, immediately to the east of Mussel Island. The New Bay sequence contains conglomeratic argillite in addition to tuffaceous sandstone turbidites and dacite flows. The conglomeratic argillite includes pebbles and small blocks of rhyolite porphyry, green chert, quartz greywacke, and black argillite. Mussel Island is composed of cleaved argillite that surrounds large, disjointed slump blocks of buff tuffaceous sandstone and rocks with familiar disrupted siltstone bands. Directly westward on the Lewisporte Peninsula, typical Dunnage Mélange lithologies outcrop continuously northward along the coast.

Relationships between lithologies similar to those on Freake Island are obscured by structural complexities on the Michael's Harbour Peninsula. At the northern end of the peninsula, gritty, conglomeratic argillite, with rhyolitic porphyry fragments, contains a large (50 m) slide lentil of chaotically jumbled basic volcanic flow rock and massive greywacke with interbedded mudstone. Beneath this slide lentil, a 12 cm décollement separates the slide lentil from conglomeratic argillite containing volcanic knockers up to 5 m long and limestone cobbles and boulders up to one meter in length. This chaotic succession is capped by a gabbro sill, ten meters of conglomerate, and boudinaged massive New Bay - type greywacke. Similarities between this succession and basal exposures of the Dunnage described above, along with geographical location of these rocks, suggest this is the basal transition zone between the mélange and the New Bay Formation, though the full sequence is not discernable due to structural complications.

On the Campbellton Peninsula, the contact between the Dunnage and the New Bay is not exposed, but inferred to be conformable on the basis of lithologic similarity between the units where they are exposed, and parallelism of their structural trends (fig. 2).

Thus the base of the Dunnage is exposed over only a relatively small part of the total length of the formation. All the exposures are grossly similar and indicate a conformable transition between the New Bay Formation and the Dunnage Mélange. The local stratal sequence at each exposure is distinct from other exposures, suggesting the transition from the New Bay to the Dunnage to be an interdigitation of the two units rather than a simple bedding plane relationship. This interdigitation is marked by a transition zone that is characterized by 1) the presence of basic volcanics as at James Island, Stanhope and Michael's Harbour, 2) the increased intensity of cleavage upwards in the section from the New Bay into the Dunnage, as observed at all localities, 3) the presence of a rhyolite porphyry bearing pebbly mudstone or conglomeratic argillite, and 4) the continuity up section of mélange lithologies as observed at Stanhope and Mussel Island.

The transitional contact between the Dunnage and the New Bay Formation is strengthened by the presence of gabbro blocks and sills in the mélange. For although gabbro occurs throughout the regional area, it is nowhere as concentrated as in the New Bay Formation. Gabbro blocks within the mélange are confined to areas proximal to the New Bay, and strike parallel to the regional trend of the same formation (fig. 2). This spatial distribution and orientation strongly indicates that the gabbro blocks are disrupted and attenuated sills derived from the New Bay Formation.

Portions of the Dunnage matrix may also be derived from the New Bay Formation. Attenuated and disrupted siltstone beds occur on Upper Black Island, Thwart Island and at all exposures of the transition zone between the Dunnage and the New Bay, as well as being widespread throughout the southwest portion of the melange matrix. Again, the limited distribution of this feature suggests a genetic link between the two units.

Thus the Dunnage Mélange overlies and interdigitates with the New Bay Formation at westerly exposures.

3-3.2 The Sansom Greywacke and its relations with the Dunnage Mélange

The Sansom Greywacke is an extensive flysch unit that represents the Upper Ordovician to Lower Silurian infilling of a marine basin. This unit represents a grossly coarsening upward sequence that is overlain and intertongues with Silurian conglomerates, (Horne, 1968).

This flysch sequence is typified by thin to medium bedded greywacke and grey to black argillite with associated chert, cherty conglomerate, pebbly arenites, carbonate, manganiferous mudstones, and less commonly olistostromes and minor occurrences of basic volcanics. Almost everywhere, the Sansom Formation displays distinctive, complex slump folding and intraformational slump blocks.

The Sansom Formation outcrops over substantial portions of the Bay of Exploits and New World Island and is largely correlative with the Point Leamington Greywacke to the west. Within the field area, the Sansom Greywacke outcrops only on Knight's Island, though it occurs on many islands to the northeast of Knight's Island and on Hummocky Island immediately northwest of the field area.

Strata on Knight's Island have been classified as Sansom Greywacke of the original Exploits Series (Heyl, 1936) and later relegated to the black shale division of Patricks' Exploits Group (Patricks, 1956). Rocks on the northern portion of the island are considered here as Sansom Greywacke solely on the basis of lithologic similarity with the unit elsewhere in Notre Dame Bay, whereas rocks on the southern portion are included in the Dunnage Mélange due to their chaotic nature.

The contact between the Dunnage Mélange and the Sansom Greywacke on Knight's Island is exposed at only two-localities along the coast. These are the only exposures along strike of the melange that reveal relationships between the Dunnage and Sansom Formations, as elsewhere granodiorite intrusion obliterates this contact, or a Caradocian black shale unit separates the two formations.

On northern Knight's Island, well above the contact with the mélange, the Sansom Greywacke is medium bedded and in places interlayered with thick intervals of black shale. Locally, thin siltstone beds are manganese rich. These bedded sediments display a spectrum of mass gravity movements, most impressive of which are large scale slump folds and huge, bedded intraformational slump blocks and slide lentils (pl. 21).

Volcanic activity in this succession is represented by two thick (8 m) zones of green, chloritic pillow lavas and flows with flow top breccias. Greywacke beds in the immediate vicinity of the base of these flows contain well developed slump folds and a high concentration of tuff.

On the east shore of Knight's Island, chaotic greywacke and argillite of the Dunnage Mélange are in fault contact with more coherently bedded Sansom lithologies. The fault is marked by a black, smeared gouge with attenuated, disrupted siltstone bands common on the Dunnage side and brecciated Sansom strata immediately to the north of the fault.

On the west side of the island, opposite this contact, Sansom lithologies continue south of the fault suggesting it is of minor significance. Rocks on this side of the island have a strained, semi-schistose aspect due to tectonization by the Long Island batholith that is marginal to the west shore of the island. South, along the coast, lithologies display an overall decrease in grain size, accompanied by a deterioration of continuous bedding. Continuing south, approaching the contact between the melange and the greywacke, small greywacke olistoliths (pl. 22) and subtle isoclinal slump folds become a regular feature of the strata. Below a boudinaged greywacke lentil (pl. 23) bedding is not a continuous structure in the rocks, as only vestiges of bedding lend a vague, ghost stratigraphy to the section. This greywacke lentil is chosen as the contact between the Sansom Formation and the Dunnage Mélange to the south. Typical mélange containing greywacke boulders and volcanic blocks outcrops south of this section.

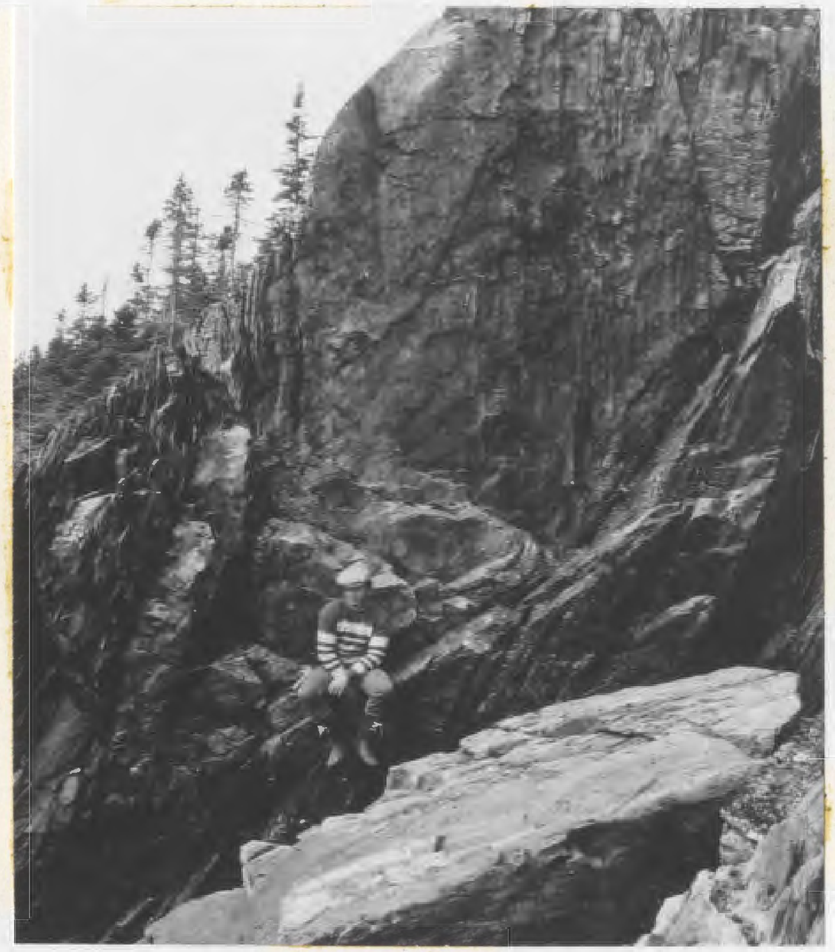


Plate 21: Large slide block within the Sansom Greywacke, northern Knight's Island. Bedding is overturned and continuous around the block, suggesting a surficial slump as the origin of the block

Plate 22: Small greywacke olistolith in bedded mudstones of the Sansom Greywacke, west shore of Knight's Island. This location is about 20 m above the contact between the Dunnage and Sansom Formations

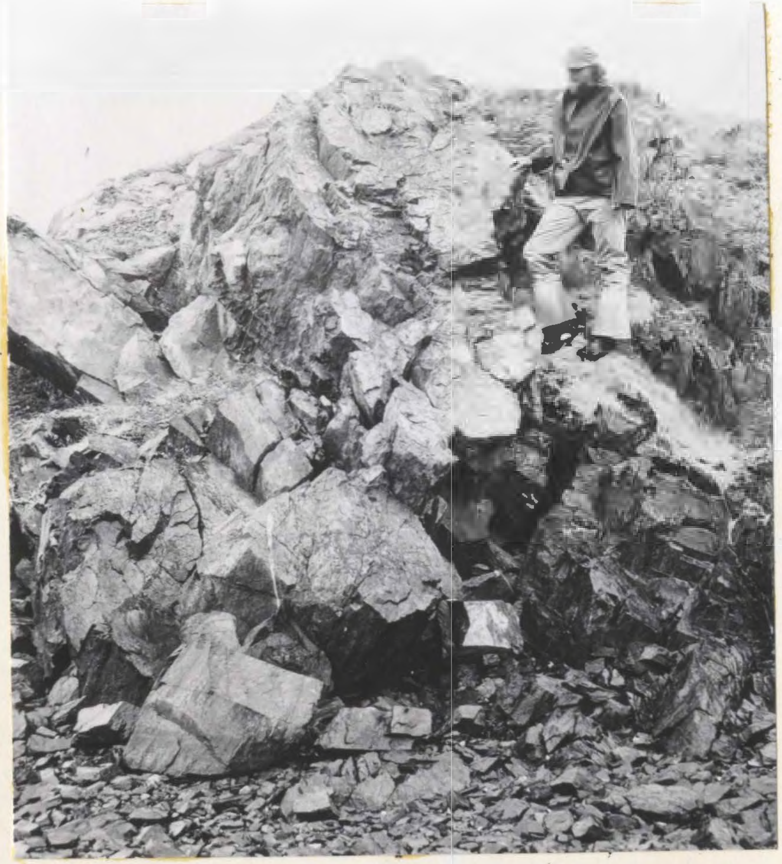


Plate 23: Boudined, yet continuous, greywacke bed that is the contact between the mélange and overlying Sansom Greywacke on the southwest coast of Knight's Island. Note the internal brecciation of the greywacke.

Plate 24: Sharp contact of the Long Island granodiorite with country rock, east coast of Birchy Island

The relationship between the Sansom Greywacke and the Dunnage Mélange is thus a depositional contact, where the top of the mélange grades upward through a transition zone, into bedded greywacke. To the northeast, in Dildo Run, the Dunnage, containing basic volcanic blocks, is bounded by the Dark Hole Formation, a Caradocian black shale unit that conformably separates the mélange from the Sansom Greywacke (Williams and Hibbard, 1976). Westward, a Caradocian black shale unit separates Lawrence Head basic volcanics from the Point Leamington Greywacke, a Sansom correlative. These relationships indicate that the Knight's Island contact infers one or more of the following; 1) the greywacke sequence on Knight's Island may be a flysch member between the Dunnage and Caradocian shales that may lie farther to the north, 2) the Caradocian unit is incorporated into the mélange in the Bay of Exploits, 3) a local facies change within the Caradocian unit, thus Sansom-like lithologies of Knight's Island may be actually Caradocian, or 4) local nondeposition or deletion of the Caradocian black shale in the Bay of Exploits.

3-3.3 Regional relationships and summary

The southwest portion of the Dunnage Mélange is in conformable, transitional contact with surrounding units; the base of the mélange interdigitates with the New Bay Formation, the top of the mélange is in sedimentary contact with the overlying Sansom Greywacke. These relationships are strengthened by the similarity of mélange block lithologies and rock types of the New Bay and Lawrence Head Formations of the middle Exploits Group

Disrupted siltstone bands and blocks of gabbro and greywacke that are identical to lithologies in the New Bay indicate a source area for these mélange features in this unit of the middle Exploits Group. In the mélange, these lithologies are limited in extent to the southwest portion of the Dunnage, and concentrated in the basal areas of the mélange.

West of the Bay of Exploits at Fortune Harbour Peninsula, the New Bay Formation is overlain by the Lawrence Head Formation. Gabbro sills within the New Bay are believed to be feeders to the Lawrence Head volcanics. The same stratigraphic sequence is observed in the Dunnage, where gabbro is confined to basal areas of the mélange, and basic volcanic blocks form a broad zone across the upper part of the mélange. The volcanics in these blocks bear close resemblance to those of the Lawrence Head; thus it is not surprising that the swath of volcanic blocks in the Dunnage projects westward into the Lawrence Head Formation at Upper Black Island and at Lawrence Head (fig. 5), inferring lateral equivalency of these units.

Mélange matrix shales may have a composite source in both the New Bay and Lawrence Head formations, as suggested by local lithologic similarities such as thin disrupted siltstone bands and bedded green and black argillites attached to a volcanic block in the mélange. Neither the New Bay nor the Lawrence Head contain the substantial amounts of argillite that compose the Dunnage Mélange, inferring that the matrix may be a finer grained, distal equivalent of these units.

The Middle Exploits Group is capped by a veneer of graptolite bearing, Caradocian black shales that directly overlies the Lawrence Head Formation. This same relationship is observed in Dildo Run, where the Dunnage Mélange, containing basic volcanic blocks, is inferred to be conformably overlain by Caradocian Dark Hole black shales (Williams and Hibbard, 1976). This relationship also supports the lateral equivalency of the Dunnage and the Middle Exploits Group. In the Bay of Exploits, the Dunnage is in sedimentary contact with the Sansom Greywacke. In light of stratigraphic evidence to the east and to the west, this unique contact infers an erosional surface or a lateral facies change.

Carbonate blocks and quartz-rich greywacke blocks in the Dunnage hint at a source terrane for these blocks, to the northwest of the melange, in the Summerford Group and Cobbs Arm Limestone. Structural relationships between the Dunnage and these groups are vague at this time.

The Dunnage interdigitates with and internally mimics the stratigraphy of the middle part of the Exploits Group. Available evidence indicates a sedimentary contact between the top of the mélange and the overlying Sansom Greywacke in the Bay at Exploits, as well as with Caradocian black shale to the northeast in Dildo Run. The latter relationship is the same as that at the top of the middle Exploits Group. Therefore the Dunnage Mélange is a lateral, possibly distal, chaotic equivalent to the middle Exploits Group (fig. 7).

3-3.4 <u>Effects of granodiorite intrusion</u>

Two granodiorite batholiths truncate and thermally metamorphose the southwest portion of the Dunnage Mélange along its northwest and southeast borders. The Long Island batholith, which bounds the Dunnage to the northwest, is centrally located in the Bay of Exploits. It is nested in the core of a regional syncline, where it assumes an ellipsoidal shape. The Loon Bay batholith, to the southeast, outcrops over a large portion of the Comfort Cove Peninsula, and for 25 km. eastward. The

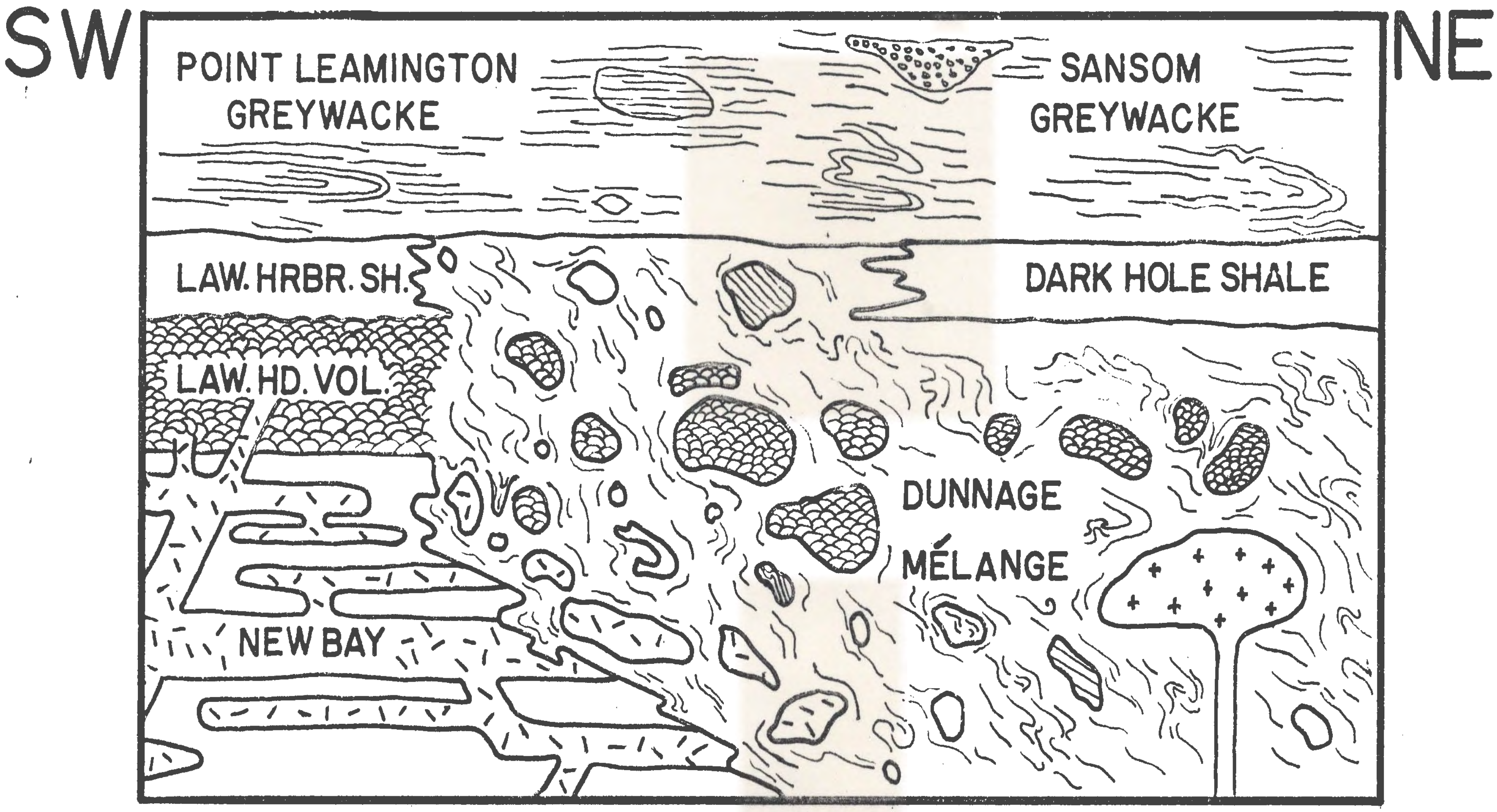


Figure 7: Schematic representation and summary of relationships between the Dunnage Mélange and surrounding units (see text)

two batholiths are lithologically similar and are probably continuous beneath the waters of the Bay of Exploits, as a small satellite, or more likely a cupola of granodiorite outcrops on the southwestward part of Sivier Island.

The granodiorite is mineralogically and texturally variable. The chief minerals are quartz, plagioclase, orthoclase, biotite and hornblende, with accessory sphene. The amount of hornblende and biotite varies considerably from area to area, and the minerals are locally altered to actinolite and chlorite, respectively. The granodiorite is commonly medium- to coarse-grained with hypidiomorphic granular texture, though in places it abruptly becomes porphyritic such as on Sivier Island and in road exposures on the Comfort Cove Peninsula.

Recent K/Ar dates indicate ages of 372 $\pm$ 10 m.y. and 365 $\pm$ 10 m.y. for the Loon Bay batholith (Kay, 1974). Therefore the granodiorite substantially post dates mélange lithologies.

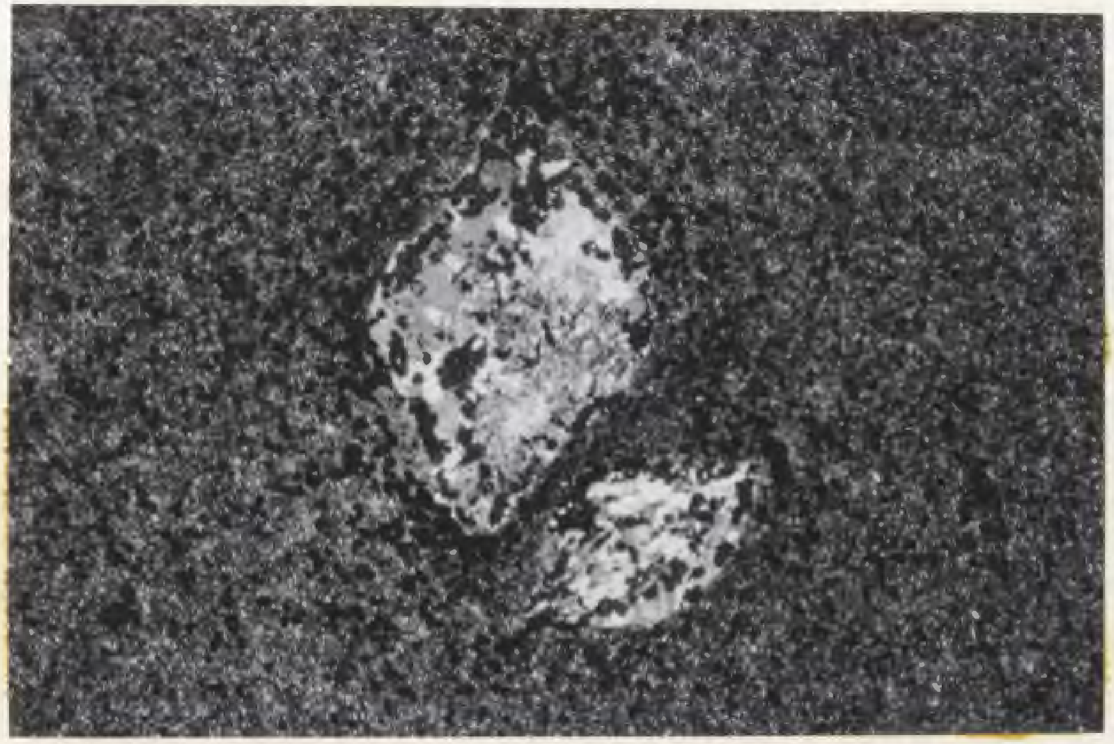
All of the contacts of the granodiorite with the mélange and surrounding units are sharp and abrupt (pl. 24). In places, such as on the coast north of Campbellton, on the west side of Knight's Island, and at Southern Head, the country rock has been deformed and recrystallized by intrusion to form semi-schists (see pl. 49).

All of the Dunnage Mélange in the field area has been thermally metamorphosed by the granodiorite. The common contact metamorphic minerals in clastic sediments are biotite + cordierite + garnet (spessartine) and in carbonates, calcite + tremolite + diopside. Common basic volcanic mineralogy is actinolite + chlorite + albite in a highly sericitized mesostasis. The chemistry of these volcanics also reveals that they are highly altered (Appendix II) though on a CNK plot (Appendix II), a linear relation suggests a consistent alteration. All of the gabbro in the field area is altered, typically containing 50% sericitized plagioclase, with subordinate amounts of biotite and clinopyroxene that is uralitized to actinolite and chlorite in most places. Original hornblende, orthoclase and orthopyroxene are rare or absent.

Thermal metamorphism is responsible for garnet rinds on disrupted siltstone bands, garnet clusters, and angular quartz segregations. All disrupted siltstone bands in the area exhibit thin rinds around attenuated beds that in thin section are observed to be composed of garnet. These rinds are probably due to chemical migration within these bedding remnants during thermal metamorphism.

Garnet clusters (plts. 25, 26) are common in the argillite matrix of the mélange, particularly near the manganiferous section on Camel Island. These clusters are round to ellipsoidal and this form suggests that they were originally sedimentary concretions. Their resemblance in form and composition to manganese pellets (plts. 10, 11) would suggest that the latter structures may have a similar origin rather than having formed as shear pellets. Similar garnet clusters have been reported from the Garnetiferous Beds of the Leinster Granite Aureole, and are also interpreted as representing small sedimentary concretions (Kennan, 1972).

Quartz pods are very prominent in outcrop (plts. 8, 27) and are confined to tuff and siltstone blocks and greywacke intrablock breccias, suggesting that they were once fragments of silica rich sediments or were produced as a metamorphic segregation feature. That they are formed by thermal metamorphism is confirmed by a laminated siltstone-tuff block in Dildo Run, northeast of the field area. Here the block is thermally metamorphosed on one side by a diabase dike, exhibiting



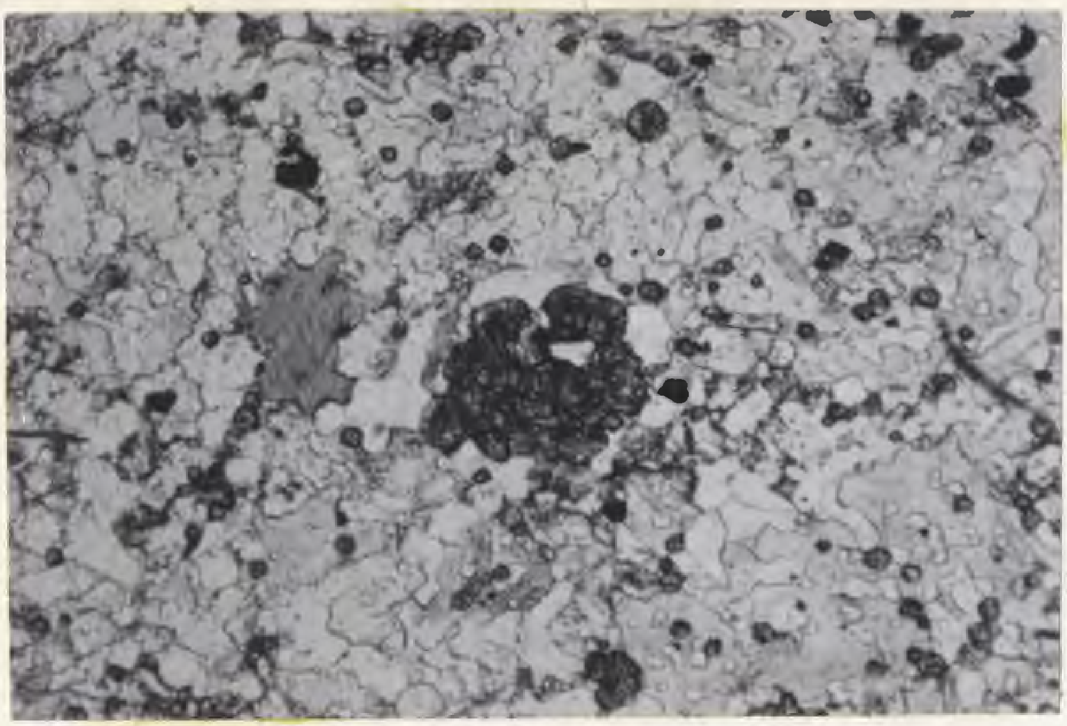


Plate 25 & 26: Garnet clusters in shale matrix (25) and quartz rich matrix interbed (26). These were probably sedimentary concretions altered by hornfelsing. (25, x nicols, X 10; 26 un x nicols, X 16)

Plate 27: Angular quartz inclusion within hornfelsed block of laminated tuff and siltstone

Plate 28: Regional mélange terrane structural features displayed in an outcrop of attenuated and disrupted siltstone, south shore, Salt Pond

the angular quartz segregations, whereas the other end of the block (15 m distant) is unmetamorphosed and devoid of quartz clasts.

Thus contact metamorphism added the final touches to the character of the southwest portion of the Dunnage Mélange.

IV. STRUCTURE OF THE SOUTHWEST PORTION OF THE DUNNAGE MÉLANGE

The Dunnage Mélange exhibits a variety of deformational features that range from syndepositional and soft rock structures to regional penetrative cleavage, folding, and faulting. These structures can be attributed to forces acting during two broad deformational periods, the first encompassing a soft rock phase and the second a hard rock phase. The mélange attained its primary chaotic aspect during the initial soft rock deformational phase; additional minor internal disruption accompanied the later hard rock penetrative events.

4-1 Soft rock deformation within the Dunnage Mélange

The Dunnage Mélange exhibits the extreme effects of soft rock deformation that are responsible for the discontinuous structural style of the terrane. The discontinuous nature of soft rock structures, in general, as contrasted to the geometrically consistent style of hard rock structures, is due to large ductility contrasts between constituent lithologies at the time of deformation. These ductility contrasts can be inferred from structures in the melange at all scales, from the matrix and smaller sedimentary inclusions up to large sedimentary blocks. Sedimentary lithologies sustained most strain during soft rock deformation and igneous components are relatively undeformed.

4-1.1 Zones of sedimentary inclusions and sedimentary blocks

Zones of sedimentary inclusions and larger sedimentary blocks exhibit, at successively greater scales, the disharmonic deformational style of the mélange terrane. These zones, in order of magnitude of scale, are marked by familiar disrupted siltstone bands exhibiting small scale soft sediment deformational structures, conglomeratic argillites that represent intermediate size structures, and large scale sedimentary blocks and lentils.

On the southern shore of Salt Pond Cove, an outcrop of thin, chaotic siltstone bands displays, on a small scale, the basic discontinuous structural style that dominates the entire mélange terrane (pl. 28). Extensional soft rock deformational structures are common in this outcrop and include attenuation and boudinage of beds, extreme stretching that yields isolated bedding fragments, and slump folding of individual beds and groups of beds. A few cases of wedged beds indicate only local compression during deformation. From these features it can be deduced that the structureless matrix around these interbeds was much more ductile than the beds that are plastically deformed.

Outcrops of bouldery, conglomeratic argillite are typified by fissile, rubbly argillite enveloping rounded, resistant sedimentary blocks (pl. 29). These features attest to the intense extensional strain history of this portion of the mélange. Their aspect suggests extreme boudinage, where a sequence of intercalated greywacke siltstone, and argillite was disrupted and greywacke and siltstone beds were stretched and spalled about to form blocks in an argillite matrix. Again, a distinct ductility contrast, at the time of deformation, is apparent between the matrix and inclusions.

Features common to these zones of sedimentary inclusions are also displayed on a larger scale by greywacke lentils and blocks. Typically, lentils are plastically mega-boudinaged (plts. 23, 30) and in extreme cases form isolated boudins (pl 31). Undoubtedly this boudinage is a soft rock process, for as noted by Wood (1974) at Anglesey, "... ductility contrasts between the materials and the mean ductility of all the materials

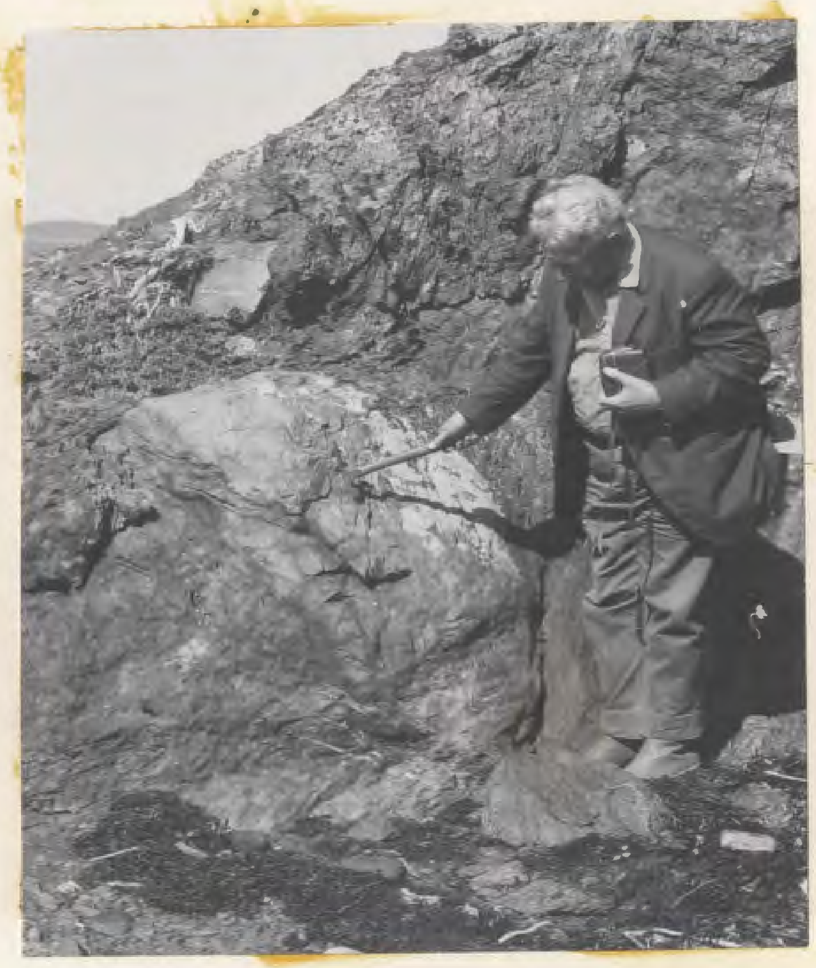


Plate 29: Rounded greywacke boulder plastered with black shale in conglomeratic argillite, Foulke Cove. The angular block above the rounded boulder is a rarity in these bodies.

Plate 30: Mega-boudinage of a greywacke lentil, just south of Foulke Cove

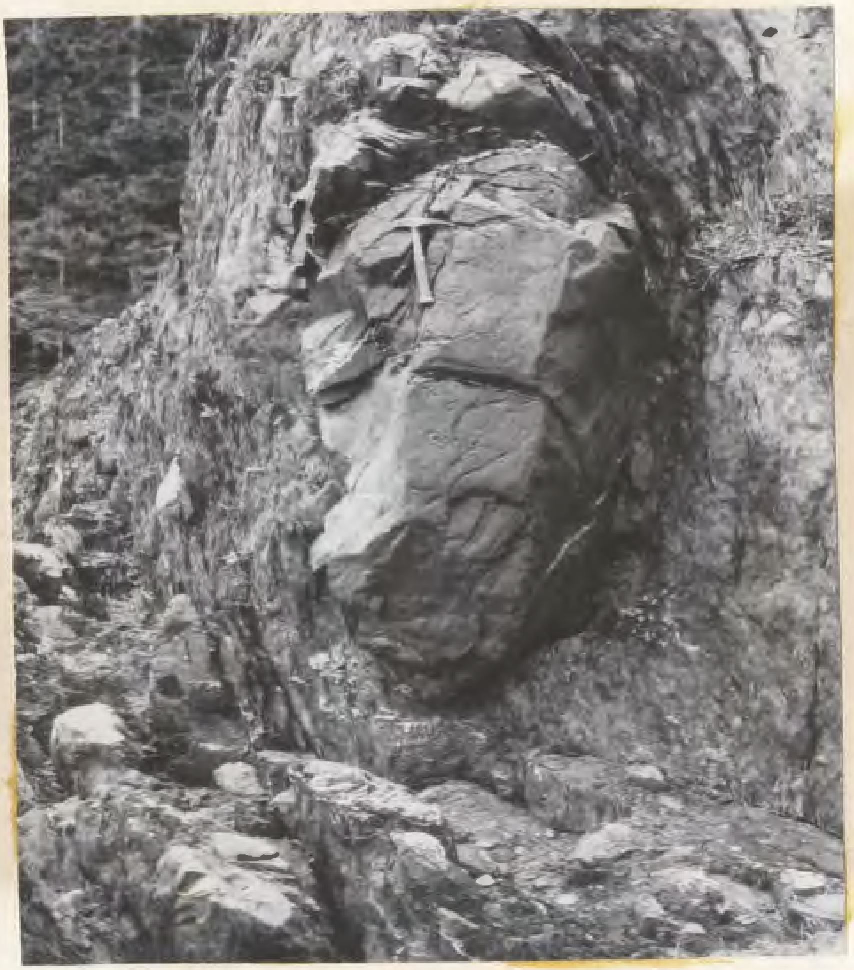


Plate 31: Extreme boudinage of greywacke lentils yields individual, rounded and faceted blocks such as this one, on the west coast of the Comfort Cove Peninsula

involved would need to be impossibly high ..." to produce such features by hard rock deformation.

The matrix surrounding large blocks exhibits structures that are minute or non-existent at smaller scales. These structures vary according to the matrix lithology.

On the south coast of Sivier Island, a pink, fine grained sandstone is sandwiched between a siltstone bed and a greywacke lentil (pl. 32). The sandstone is lobate, indicating that it has been completely hydromobilized (i.e., became fluid post-depositionally) to form a fluid slide plane between the two slabs.

Near the base of the bedded sedimentary section on Camel Island, the mélange matrix contains attenuated, thin (1 cm.), fine-grained sandstone to siltstone interbeds. These have been partially hydromobilized as indicated by the irregular, fluid, and in places indefinite boundaries of these beds. Upon mobilization, the beds were stretched parallel to the local cleavage and extreme attenuation produced isolated bedding discs, or shear pellets (pl. 33). The discontinuity of structures, apparent even in hand sample, attest to the differential fluid content and hence, ductility contrasts, at the time of deformation, of these beds among themselves and between the beds and the matrix. These structures may mark a zone of intense strain related to movement of the Camel Island bedded section within the matrix. Manganiferous pellets (plts. 10, 11) farther up in this section may represent extreme shearing of manganese rich layers, yielding isolated discs. Elliston (1963a, b) has described similar structures from Australia and called such rocks shear, or pelletoid conglomerates. He proposed the sheared and isolated discs represent cleavage segments in strained, semi-consolidated sediments.

Plate 32: Lobate form of sandstone on south coast of Sivier Island, suggesting this lithology was once fluid, acting as a slide plane between greywacke and siltstone

Plate 33: Discontinuous structures typify interbedded fine-grained sandstone and mélange matrix near the base of the Camel Island bedded section. Note the vague, fluid boundaries of the interbeds and the presence of isolated pellets

Plate 34: Plastic décollement zone in shale beneath greywacke slab, Northwest Bottom

Elsewhere in the mélange, the matrix is plastically folded and sheared, forming décollement zones beneath larger blocks (pl. 34).

Thus, zones of sedimentary inclusions, larger sedimentary blocks, and even the matrix display, at many different scales, soft sedimentary deformational structures that demand extreme ductility contrasts between constituent lithologies. These structures are dominantly extensional in nature, indicating that compressional force was, at most, a minor factor during mélange formation. It is the aggregation of extensional soft rock features that controls the structural mosaic of the Dunnage Mélange.

4-1.2 Recycled blocks

Many blocks and lentils within the mélange are internally disrupted in a manner similar to the structural style of the whole terrane. The internal chaos of the blocks indicates that they have been through an earlier soft rock deformational phase prior to final emplacement into the mélange. Thus, these are termed recycled blocks. They are represented in the Dunnage by conglomeratic argillite blocks, zones of pebbly mudstone, greywacke intrablock breccias, and internally slumped siltstone-tuff blocks.

At a few localities along the west coast of the Comfort Cove Peninsula, blocks of chaotic, conglomeratic argillite are found. These may be more commonplace than realized, as they are similar to the mélange matrix and only at excellent exposures can the boundaries of these rafts be discerned. The blocks on the Comfort Cove Peninsula are typified by boudinaged and broken beds of tuffaceous sandstone surrounded by a more ductile, cleaved, black shale matrix. The disrupted sandstone beds are generally rounded and elongate, parallel to the cleavage in the black shale matrix. Thus a phase of conglomeratic argillite formation occurred before or during mélange formation. The incorporation of these blocks into the mélange infers that locally, the mélange matrix reacted plastically.

Zones of pebbly mudstone are not confined to well defined blocks in the mélange, rather they intermingle and form discrete patches in the black shale matrix, such as exposed on the coastline of Burnt Bay, just north of Lewisporte. At the time of original deposition, pebbly mudstones were pebble induced mudflows. Following deposition they were recycled by mass sedimentary movements and incorporated into the mélange. In some cases, the soft sediment deformational history of these blocks is more complicated, as blocks of pebbly mudstone have been recycled within pebbly mudstone zones (pl. 36).

Greywacke intrablock breccias, as exposed at Comfort Cove, Camel Island, and Job's Cove, record a complex deformational history (plts. 8, 35). The form of these blocks infers a four phase history, including 1) a depositional stage, 2) a flow and disruption stage, 3) a stage of strain hardening, and 4) a period of plastic deformation. Where bedding is found in the breccia blocks, it is evident from typical Bouma features that the greywacke was originally deposited as turbidite. Following deposition, three phases of soft rock deformation may have occurred simultaneously, including 1) flow of more ductile greywacke around compacted beds that caused elastic disruption of beds to form breccia fragments, 2) some form of strain hardening that must be responsible for the preservation of well defined boundaries of the blocks, rather than fluid, wispy contacts as would be expected from the fluid greywacke component, and 3) plastic deformation that is responsible

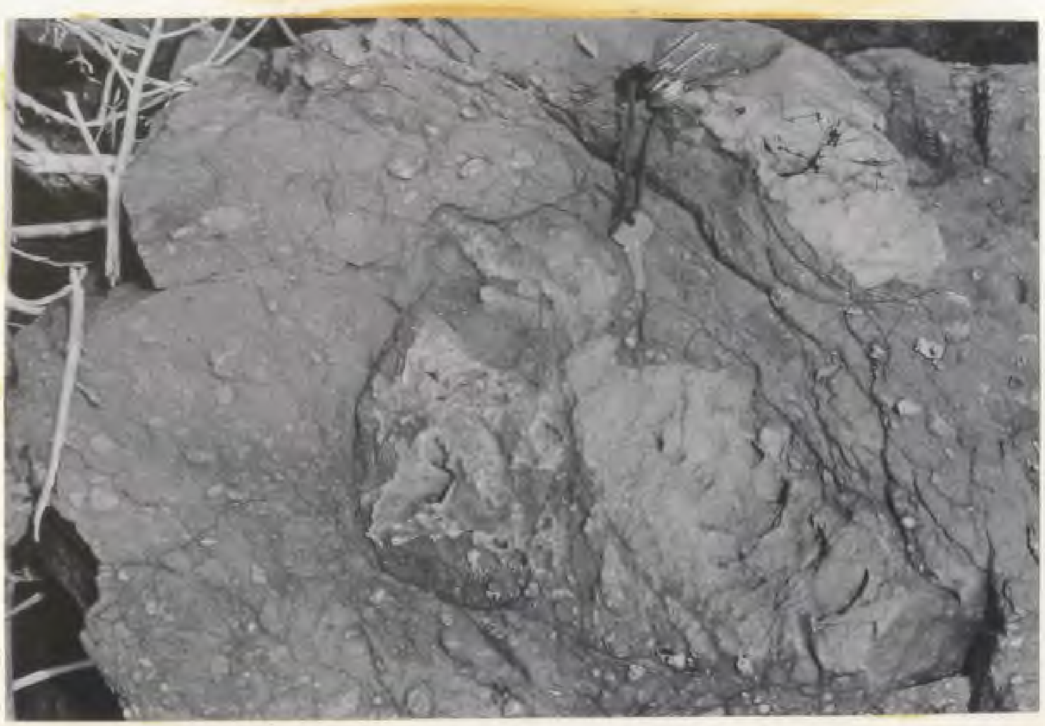


Plate 35: Greywacke intrablock breccia, Camel Island. Note the greywacke fragment cut by veinlets, bottom center.

Plate 36: Block of pebbly mudstone within a pebbly mudstone zone. Note faint foliation in block perpendicular to that in surrounding mudstone. Coast north of Lewisporte

for the isolated nature of these blocks. Almost all greywacke exhibits extensional fractures cutting transversly across beds and blocks, suggesting elastic behaviour following plastic deformation, with continued extensional stresses.

On Sivier Island and on the coast west of Shoal Tickle, bedded rafts of siltstone and tuff occur in the mélange. These blocks are internally chaotic and slump folded (pl. 37) and in some places exhibit chevron folds. Of note, is the lack of a penetrative cleavage or uniform fabric within the blocks, showing the sediments were slump folded prior to or during incorporation into the mélange. These blocks have very irregular boundaries that suggest fluid disintegration of the blocks into the melange matrix.

Recycled blocks therefore display two phases of mobilization, both of which acted upon rocks that displayed the basic ductility contrasts fundamental to mélange character. The first mobilization is represented by the internal structural disorder of the block that occurred before or during the second mobilization, which is the incorporation of these blocks into the regional mélange terrane. Thus, soft rock deformational processes were repetitive.

4-1.3 Soft sedimentary cleavage

Locally, within the Dunnage Mélange and some surrounding units, it can be demonstrated that cleavage was formed in the ductile shale matrix by soft sedimentary flowage. This process is supported by 1) the presence of cleavage in conglomeratic argillite blocks, 2) the presence of phacoidal cleavage and the close association and intensification of cleavage near hydromobile sediments, and 3) bedding-cleavage relations in strata on Upper Black Island.

Plate 37: Plastically slump folded and partially brecciated texture of siltstone-tuff interbeds in block, northern Sivier Island

The relationships of cleavage within and cleavage surrounding a conglomeratic argillite block north of Chapel Head imply a soft sedimentary origin for both cleavages (pl. 38). The cleavage within the block is steeply dipping and parallel to the alignment of severely disrupted tuffaceous sandstone beds within the block. The steeply dipping external cleavage, which truncates the internal cleavage, completely surrounds and is parallel to the perimeter of the block. The internal cleavage must pre-date the external cleavage and record a mobilization of the block that is earlier than the mélange formation. The style of deformation within the block indicates soft rock disruption, which is also the most likely cause of its internal cleavage formation.

Recycling of the block into the mélange was also accompanied by soft sediment flow and further cleavage formation in surrounding matrix. The configuration of the external cleavage that everywhere parallels the perimeter of the block indicates an origin by the movement of the block within soft shale, as cleavage formed by compression would form auge around such blocks. Abbate, et. al. (1970) report similar cleavage-block relationships in the argille scagliose of Italy, and arrive at the same interpretation.

Phacoidal cleavage, that is, cleavage that bounds shale phacoids, or pellets, is developed to varying degrees in the mélange matrix (pl. 39). In places, the matrix shales display associated flow-features, particularly fluidal wisping of finer grained lithologies. Formation of phacoidal cleavage depends upon the application of stress to soft, ductile sediments, producing sigmoidal tension fractures that result in shale phacoids (fig. 8) (Elliston, 1963a). Thin, attenuated beds at the base of the Camel Island bedded section may represent a

Plate 38: Internally chaotic argillite block (above and behind hammer) with internal cleavage at a high angle to cleavage in the surrounding mélange matrix. Cleavage in matrix is everywhere parallel to block boundaries. West coast of the Comfort Cove Peninsula

Plate 39: Incipient development of phacoidal cleavage, north of Lewisporte

Plate 40: Mudflake conglomerate with imbricated shale fragments, New Bay Formation, Cat Island

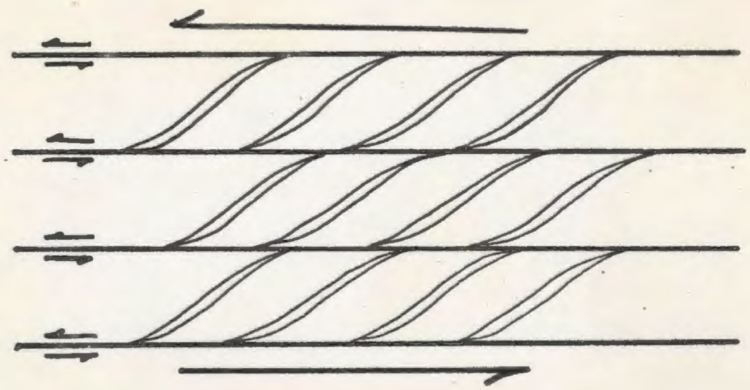


Figure 8: Development of phacoidal cleavage and phacoidal pellets (see text) (from Elliston 1963a)

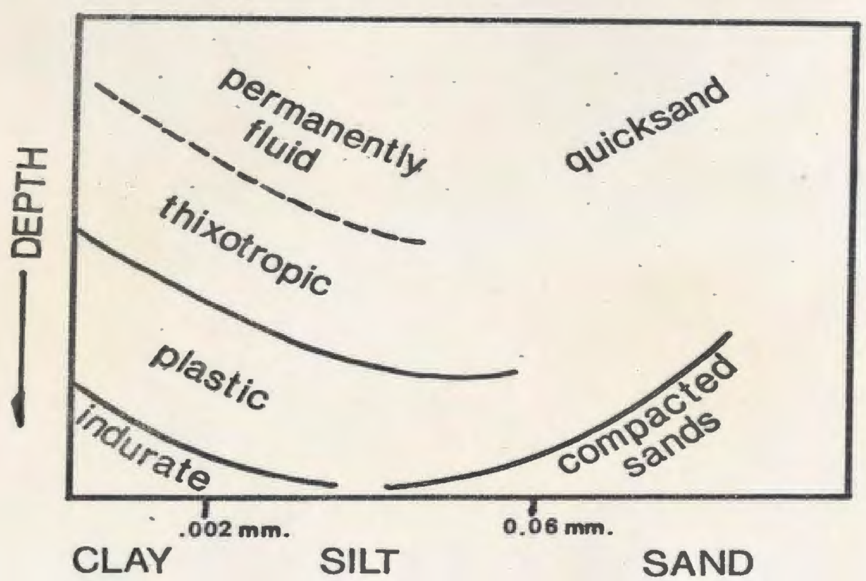


Figure 9: Schematic illustration of rheotropic zones in relation to depth below sea floor and sediment grain size. (from Boswell, 1961)

variation of this process in which more stress was applied to more fluid rocks, as shear discs, or flow phacoids, are parallel to a marked cleavage. Manganiferous pellets (plts. 10, 11) farther up in this section and other, irregular, patchy, and elongate clumps of argillite in the mélange matrix may also be associated with phacoidal cleavage development.

Cleavage is locally intensified in other areas of hydromobile flow, such as at the base of the Dunnage at Stanhope and at Rice Island, suggesting a soft sediment origin, at the base of a submarine slide, for this cleavage.

Within Caradocian strata, on Upper Balck Island, bedded, fine-grained mudstone interfingers abruptly with phacoidally cleaved argillite, suggesting a soft sediment cleavage formation due to flow or failure of the beds. This mimics, on a smaller scale, the relationships between the bedded New Bay Formation and the Dunnage Mélange.

Therefore, within the Dunnage and some surrounding units, it is clear that soft sediment flow can form divisional planes that are characterized by an alignment of material, as has been shown for other areas (Elliston, 1963a; Maxwell, 1963; Moore and Geigle, 1974). The extent to which this has occurred, other than in local areas, is conjectural, as these early features are over-printed by a penetrative cleavage.

4-2 Soft rock deformation in surrounding units

The Dunnage Mélange lies in the central part of a continuous stratigraphic sequence where soft rock deformational features are the rule rather than the exception. Soft rock deformation of a less intense nature than that of the mélange is evident within the New Bay and Sansom Formations.

The New Bay Formation contains abundant structures that can be attributed to surficial slumping or fluid mobilization of sediments. Common features that were formed at or near the depositional surface include turbidites and pebbly mudstones. Turbidites displaying typical Bouma sequences, are attributed to rapid and fluid deposition of sediments by turbidity currents. Pebbly mudstones are typified by rounded pebbles scattered in a mudstone matrix. The deposition of pebbles into soft mud, resting at a slight incline, triggers viscous, slow moving, to rapid, slurry-like mudflows that churn pebbles and matrix together (Crowell, 1959). Presence of these features in the New Bay Formation typify the down slope sedimentary movements prevalent in the regional sedimentary sequence. Vestiges of both turbidites and pebbly mudstones can be recognized within the Dunnage Mélange.

A less common surficial feature, mudflake conglomerate (pl. 40) is typical of the turbidite sequences at Freake Island, Cat Island, and Michael's Harbour. These conglomerates consist of imbricated black argillite fragments set in a black argillite matrix. Locally, the matrix exhibits flow structure, and fluid contacts with underlying strata. These features, along with the similarity of matrix and included flakes suggest an intermediate stage of flow, relative to the rapid turbidity currents and sluggish mudflows. These same features are reported by Elliston (1963a, b) from sediments in the Warramunga Geosyncline of Australia.

Elsewhere, thick (30 m) massive units of the New Bay Formation are internally chaotic, with remnants of bedded greywacke, small boulders, and hook shaped slabs of greywacke strewn together. A typical example occurs on the east coast of Thwart Island (pl. 41). At other places on

Plate 41: Hooked greywacke bedding slab in massive chaotic unit, New Bay Formation, Thwart Island

Plate 42: Fluidal wisping and elastic wedging of siliceous argillite, New Bay Formation, Thwart Island

Thwart Island, mudstones and thin bedded silicic argillites exhibit fluidal wisping and streaking (pl. 42). These features indicate fluid sediment movement after deposition and burial.

Spectacular examples of mass sedimentary movement are also evident above the Dunnage, in the Sansom Greywacke. On Knight's Island, slump folding is particularly well displayed in many exposures of the Sansom, as are large scale bedding slips. Many of these slump folds go unnoticed without careful scrutiny, due to their tight nature and, in some places, large scale. Bedding plane slips in the Sansom are common on the northeast coast of Knight's Island and represent surficial slip features, as continuous bedding bounds these blocks on all sides (pl. 21).

Structural analysis and review of fold geometries in the Sansom Greywacke have been carried out on southwestern New World Island by Horne (1969), and similar studies in the Point Leamington Greywacke, a westerly Sansom correlative, have been described by Helwig (1970). Both workers noted the importance of slump folds as soft rock features, rather than hard rock tectonic folds.

In contrast to the Dunnage Mélange, the New Bay and Sansom Formations display less variety in soft sedimentary deformational features that imply a relatively modest intensity of strain. This is a result of the greater ductility contrasts of the constituent lithologies of the mélange compared to those found in the surrounding units.

4-3 Interpretation of soft rock deformation features

The very nature of the Dunnage Mélange can be attributed primarily to soft rock deformation of lithologies of distinct ductility contrasts. Lithologies that display such high ductility contrasts are normally considered in terms of rheotropy, rather than ductility, which is generally reserved for discussions of lithified rocks that display more similar responses to stress. Rheotropy is the ability for a material to change from a gel (jelly like solid) to a sol (solution) or a more fluid gel, as a result of a mechanical disturbance.

Boswell (1961) has classified zones of rheotropy in submarine sediments in a very general manner, being cognizant of the fact that deposits vary in stages of compaction depending on local conditions; thus anomalously high fluid pressure in a shale layer could cause a slurry to form under lithified sediments (Hubbert and Rubey, 1959). Boswell (1961) has recognized four rheotropic zones (fig. 9), the permanently fluid, thixotropic, plastic, and indurate that are distinguished by two boundaries of physical behaviour, the fluid limit and the yield limit (Dott, 1963). The fluid limit is the boundary between plastic behaviour and fluid behaviour, while the yield limit separates indurate, or elastic behaviour from plastic behaviour. Thixotropy is the change from a gel state to a sol, when stress is applied, and back to a gel upon release of stress. Materials in the thixotropic zone act as viscous fluids, thus vary in response to stress according to composition and texture.

Two variations of thixotropic behaviour that exhibit resistance to stress are false body thixotropy and shear rate blockage (Boswell, 1961). In false body thixotropy, a gel persists until a yield point, after which flow occurs, unlike spontaneous liquification of normal thixotropic behaviour. Shear rate blockage occurs when a dilatant material (i.e. one that expands and expels water under stress) is stressed, thus losing its fluid state and reacting plastically or elastically.

Structures, at all scales, in the Dunnage Mélange can be attributed to the rheotropic behaviour of sediments at the time of deformation. The discontinuous nature of the mélange can be interpreted in terms of thixotropic and plastic responses to stress, though evidence of fluid and indurate behaviour is present.

Familiar, disrupted siltstone bands imply rheotropic behaviour in the mélange matrix. The arrayment of these beds in the matrix infers thixotropic mobilization of the argillite-mudstone matrix that supported the siltstone beds, thus causing attenuation, contortion, and spalling of these beds. Similar processes, only at larger scales, can be envisaged as forming conglomeratic argillite zones and disrupting massive beds to form larger, isolated blocks.

Structures in the matrix that surround these larger blocks demonstrate the rheotropic variability of the matrix. The pink, fine grained sandstone on Sivier Island displays characteristics of a sediment that was at one time quicksand with fluid response to stress. The stretched beds in the matrix at the base of the Camel Island bedded section display contrasting, discontinuous structures that infer a more competent response to stress than the quickstone, yet more fluid than plastic movement. The contrast of structures indicates that possibly a combination of normal thixotropy and false body responses were responsible for these structures. Folds in matrix décollement zones beneath many blocks indicate that the matrix reacted plastically during soft rock deformation.

It can also be demonstrated that recycled blocks displayed at least two phases of rheotropic response during their complicated strain history. The internal chaos of argillite blocks, as exposed on the Comfort Cove Peninsula, probably had an origin similar to that of conglomeratic argillite, that is, thixotropic or false body yield of the matrix allowing plastic yield of the interbeds under initial stress. Possibly, with increased stress, these sediments underwent shear rate blockage and solidified so as to boudinage and form isolated blocks retaining sharp boundaries, rather than being completely dispersed and mixed with the matrix. Greywacke intrablock breccias display this phase particularly well, as these blocks exhibit minimal interfingering of greywacke and mélange matrix, inferring very efficient shear rate blockage. Thus, following the first cycle of slumping and shear rate blockage in these strata, plastic responses to stress permitted boudinage and the formation of isolated block, e.g. melange terrane. Many greywacke blocks are massive and display only this latter phase of response.

Pebbly mudstones are primary thixotropic features that responded to stress in ways varying from false bodies to liquid slurries. Incorporation of these bodies into the mélange infers a more fluid response of the argillite than shear rate blockage, as pebbly mudstone zones are vaguely defined; they responded less fluid than normal thixotropic yield of the matrix, as this lithology is confined to patchy areas. Thus pebbly mudstones may have acted as false bodies. Similarly, plastically folded siltstone and tuff blocks exhibit ragged, ill defined, digested borders, inferring rheotropic behaviour at the block-matrix interface. These blocks probably also acted as false bodies during incorporation into the mélange.

Thus, the matrix as well as individual sedimentary components of the Dunnage exhibited varying degrees of rheotropy that reflect varying degrees of compaction and fluid content of these sediments at the time of mélange formation. In reviewing the processes occurring during soft sediment deformation, it is evident that the interplay between thixotropic materials and those that reacted plastically played a large part in determining the character of the mélange terrane. Generally the matrix was thixotropically sensitive to stress whereas less fluid and coarser sediments generally reacted plastically, forming isolated blocks.

The contrast between the Dunnage and surrounding units is largely due to these rheotropic responses to stress, and in particular, the quantity of thixotropically sensitive lithologies mixed with more indurate rocks. Both the New Bay and Sansom Formations lack the quantity of fine-grained, thixotropically sensitive mudstones that form the matrix of the Dunnage, thus, as whole units, responded more plastically to stress than the mélange.

4-4 Mélange formation and summary

It is evident that soft rock deformation effected lithologies in varying diagenetic stages to form the major features of the Dunnage. Most of those processes that formed the mélange must have been depositional, as indicated by the following observations:

1) Formations that are underlying and laterally equivalent to the Dunnage (New Bay) and overlying the mélange (Sansom) are characterized by slump folds and surficial sedimentary structures (Helwig, 1968; Horne, 1969). Thus the Dunnage is centrally located within a sequence displaying extensive soft rock deformation.

2) The mélange has sedimentary contacts with both formations, indicating that it was deposited as a unit during or after New Bay deposition and before deposition of the Sansom Greywacke.

3) The Dark Hole Formation, locally in depositional contact and overlying the mélange in Dildo Run, is apparently of the same ductility as the mélange, but displays normal bedding rather than chaos, demonstrating mélange formation was surficial, and in this area, it formed before deposition of Caradocian shales.

This does not deny the possibility that remobilization occurred within the Dunnage after lithification, but supports the concept that the major aspects of the mélange are due to surficial slumping.

Sedimentary downslope movements obviously occurred over a long span of time, from New Bay depositional times up into the Silurian; recycled blocks within the mélange also suggest a long period of soft rock mobilization. These factors infer that the Dunnage may have formed over a long span of time as a result of a collection of many smaller olistostromes. Other factors are contrary to this concept, and suggest that the Dunnage formed as a single slump event. These are as follows:

1) The lack of continuous interbeds or marker beds in the mélange that would indicate periods of quietude between slump events.

2) The various stages of diagenesis recorded in the mélange suggest an accumulated sedimentary pile rather than short depositional periods followed by slumping from the Exploits Group. The latter process would be less likely to allow semi-lithification of the sediments.

These observations can be reconciled with a long history of downslope movement if the Dunnage is viewed as a single, progressive large scale slump that occurred amidst earlier and later smaller scale downslope sedimentary movements. The mélange, then, would have formed as a progressive, two phase process that is common to present day landslides (Hsü, 1969). The first phase is represented by a long period of mass creep, where shearing stress must overcome the cohesive strength and internal friction of the creeping mass, whereas the second phase is the detachment and actual sliding of the mass. In the mélange, the first phase is represented by internally chaotic argillite rafts and other recycled blocks. The sliding phase is responsible for the formation of the regional mélange terrane, including matrix and block dispersal. The sliding phase of formation is not envisaged as complete detachment for the whole of the Dunnage terrane, as no detachment zone is known, nor does it have a tectonic base where exposed. Rather, phase two movement is thought to have been differential throughout the pile, analogous to a deck of cards placed on a slight incline. Some cards slip out past others, but essentially the deck retains a rooted base. Thus, the mélange may be considered a failed sedimentary klippe.

This model explains the occurrence of shear rate blockage within recycled blocks; as creep gains impetus or local detachment occurs, stress increases, water is driven out causing shear rate blockage and with continued stress, plastic deformation occurs to form boudinaged, internally chaotic beds and isolated blocks.

In summary, the discontinuous or inhomogeneous structural aspect of the Dunnage Mélange can primarily be attributed to soft rock, dominantly extensional, deformation of strata due to massive slumping that occurred possibly as a single progressive event, involving rocks in various stages of lithification. Forces responsible for soft rock deformation must have existed from New Bay depositional time until the Lower Silurian, intensifying prior to the Caradocian, following which they decreased and terminated. This pattern requires an omnipotent stress acting in an unstable area of progressive uplift, causing fluid yield within thixotropic sediments. This omnipotent force is most reasonably gravity.

This interpretation of the Dunnage also demonstrates the non-sensical nature of labelling some units as strictly tectonic or depositional in origin, as the magnitude of the movements forming the mélange clearly warrant the adjective tectonic, though the processes involved are all sedimentary.

4-5 Hard rock deformation

Following lithification, the mélange has been subjected to folding and faulting that control its present disposition. Hard rock deformational features in the field area are mostly masked by the depositional chaos of the mélange, as a prominent regional penetrative cleavage is one of the only obvious hard rock structures. Folds are subtle and recognized faults are few in and around the southwest portion of the mélange.

4-5.1 Penetrative cleavage

The regional penetrative cleavage within the Dunnage generally trends east-northeast and dips steeply to the south, although near the Long Island batholith the cleavage orientation vaguely mimics the perimenter of the pluton. Blocks in the mélange are usually oriented with their long axes parallel to the cleavage (pl. 43). The regional cleavage tightens an earlier, locally occurring, nearly coplanar, soft sediment flow cleavage within the mélange (see 4-1.3). The soft sediment flow cleavage is identical to the regional flow cleavage in appearance, but can be distinguished by its mode of occurrence and associated phenomena. Locally, both cleavages are kinked.

It can be demonstrated that most of the cleavage in the Dunnage is a hard rock feature, as the cleavage 1) forms auge around contact metamorphic minerals produced by intrusion of Devonian granodiorite 2) forms auge around most blocks, 3) quartz-rich dikelets are boudinaged along cleavage planes axial planar to folded dikelets and 4) offsets dikelets without disturbing bedding.

Plate 43: Siltstone block with long axis parallel to regional cleavage

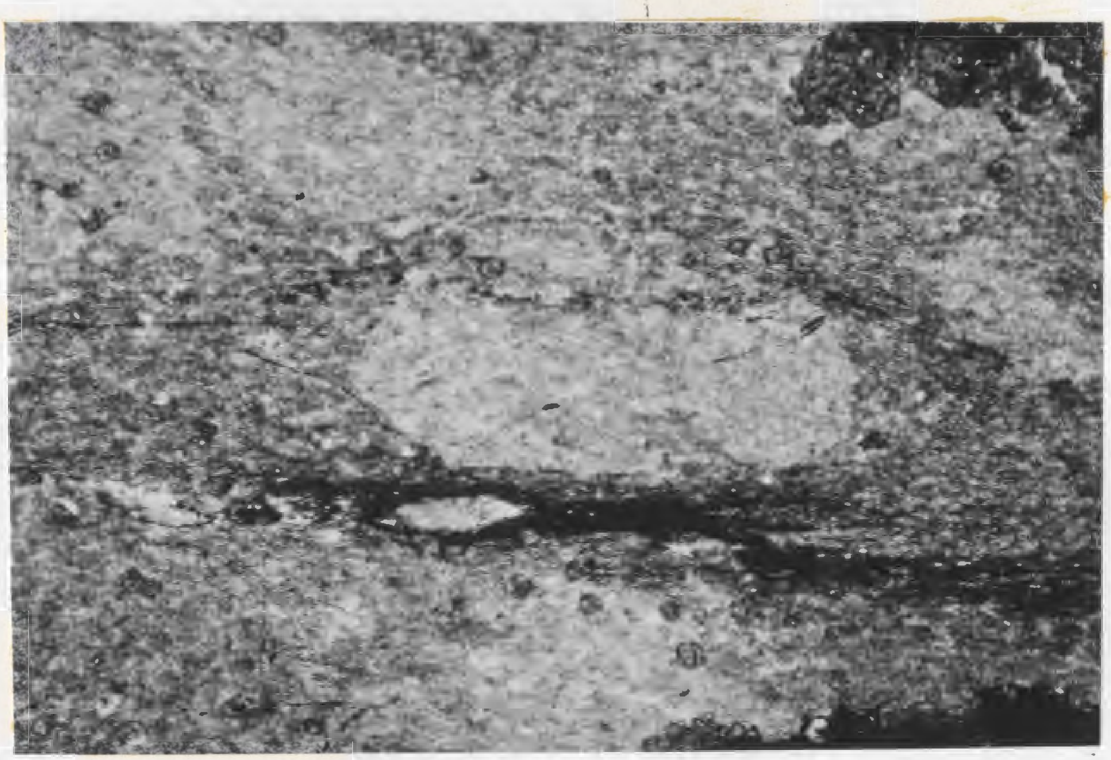


Plate 44: Photomicrograph of cleavage forming auge around contact metamorphic cordierite. (un X nicols, X 10)

In thin section, contact metamorphic garnets and cordierites exhibit pressure shadows indicating their presence prior to that of the regional penetrative cleavage (plts. 44, 45). Furthermore, in thin section, cordierites display crystallographically controlled inclusion trails generally parallel to the cleavage in the surrounding matrix. Locally, some cordierites have not been fully rotated into the plane of cleavage, thus inclusion trails are at oblique angles to the flow cleavage in the matrix, yielding strong evidence of early formation of contact minerals followed by a penetrative event. The presence of the metamorphic minerals implies a fully lithified state for the mélange, thus demonstrating that the cleavage is a hard rock feature. The contact metamorphic minerals are associated with the two Devonian granodiorite batholiths in the area (Loon Bay and Long Island), thus the cleavage is Devonian or later in age.

In many places in the mélange, cleavage in the matrix forms auge around blocks in the melange (pl. 46) suggesting a compressional event in which the matrix was viscous enough to retain the cleavage overprint. This cleavage is probably the hard rock regional penetrative cleavage that forms auge around the contact metamorphic minerals.

Quartz dikelets in the melange also record a hard rock event involving the cleavage formation. Plate 47 exhibits a boudinaged quartz dikelet, the simplest history of which may be inferred as 1) rock fracture, 2) vein injection, 3) compression, cleavage formation and boudinage. On Knight's Island, dikelets probably associated with the Long Island pluton are folded and boudinaged along cleavage planes axial planar to these folds (plts. 48, 49). Immediately northeast of the field area, on Farmers Island, quartz dikelets within

Plate 45: Microscopic view of cleavage forming auge around contact metamorphic garnets. (un X nicols, X 48)

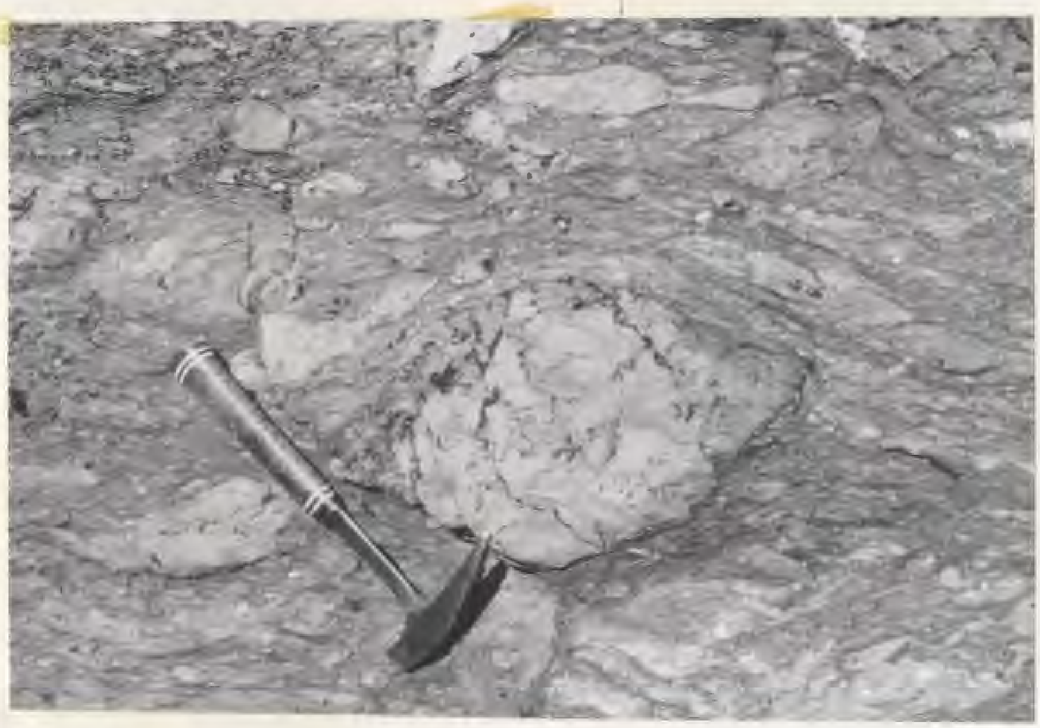


Plate 46: Typical cleavage-block relationship in mélange. Cleavage forms auge around block attesting to compressional origin of the cleavage, Comfort Cove

Plate 47: Quartz dikelet boudinaged along regional cleavage plane, later kinked. Coast north of Powderhouse Cove

Plate 48: Mechanically broken and boudinaged dikelet of the Long Island granodiorite from Knight's Island. Flow foliation internal to dikelet parallels regional cleavage planes that bound the dikelet (Sample courtesy of Dr. A.R. Berger)

Plate 49: Dikelets of the Long Island pluton displaying variable responses to compressional cleavage. One dikelet exhibits folds with axial planar regional cleavage, whereas dikelet in plane of cleavage exhibits pinch and swell features. Note the semi schistose nature of the sediments. (Photo courtesy of Dr. A.R. Berger)

Plate 50: Quartz dikelets compressionally buckled by cleavage; bedding here is unaffected, Farmers Island, northeast of field area

the Dark Hole Formation are buckled normal to cleavage, whereas bedding parallel to cleavage is locally undeformed (pl. 50), thus the cleavage here is associated with a compressional event.

Elsewhere, cleavage within the Dunnage has equivocal origins. Such is the case for cleavage axial planar to minor folds within the mélange (pl. 51). Work on recent sediments (Moore and Geigle, 1974) suggests that folds such as these could be slumps and their associated cleavage could be a soft sediment flow cleavage as easily as being hard rock penetrative cleavage.

The hard and soft sediment cleavages within the Dunnage are both identical in appearance, and in most places are nearly coplanar, yet explicitly of different origins, one due to soft rock movement, the other to a hard rock compressional event. The soft cleavage must have been coeval with Ordovician mélange formation, whereas the hard rock cleavage phase post dates the growth of contact metamorphic minerals and dikelets of Devonian age.

4-5.2 Folding

In map pattern (fig. 2) a major syncline with its axial trace trending northwest, controls the outcrop pattern from Upper Black Island, across the Lewisporte Peninsula, cradling the Long Island batholith in its core. Small scale folds within the mélange are difficult to delineate. Detailed structural analysis of the mélange terrane reveals that two phases of hard rock folding are present.

Analysis was performed by dividing the field area into seven structural zones based on cleavage and bedding orientation and plotting poles to planes of these features on an equal area net (Appendix II). Bedding and cleavage were plotted together on all projections, as

Plate 51: Fold of unknown origin in melange matrix. Cleavage could be either soft rock or penetrative. North of Stanhope Cove

Plate 52: Minor offset of Jurassic-Cretaceous lamprophyre dike, Little Burnt Bay

wherever both exist, they are subparallel. Though the number of points plotted is low, it is striking that after independent plotting of each zone, folds are revealed, the axes of which, when plotted together, represent a systematic rotation (synoptic plot, Appendix II), inferring two phases of folding; one phase is represented by folds that affect bedding and cleavage in each zone, the other by the systematic rotation of their axes. Stereographic methods are not of use in determining the true axial plane of the folds because the chaotic map pattern hides the axial traces, nor can it reveal the chronology of folding. It is interesting to note that the spread of axes of folds from each zone lies on a great circle, the axis of which plunges northwesterly at a low angle, similar to that inferred for the major syncline seen in map pattern. Thus it is possible to glean from this information that two fold phases occurred after cleavage formation, but the orientation of the axial planes remains unknown.

On New World Island, to the northeast of the present field area, Horne (1969) recognized two fold phases, one trending northeast with steep southeasterly plunging axes related to a penetrative cleavage in the area, and another, more gentle fold set that warps the first. In the New Bay area to the west, Helwig (1970) also recognized two fold phases. There, a gentle north trending set of open folds is tightened by a later northeast trending fold set that is associated with a regional penetrative cleavage. These two analyses are compatible with the fact that two fold phases are recognized in the Bay of Exploits area, but the order of occurrence remains a moot point and explanations by Horne and by Helwig are intricate and subjective.

The fold analysis in the Bay of Exploits does not appear to support data to the east and west where two fold phases also occur. However, both involve the regional cleavage rather than being related to it. This may only be an apparent affect, as during deformation of such an inhomogeneous plastic body as the Dunnage Mélange, cleavage may have been warped as it formed and then folded a second time during a later episode of diastrophism.

4-5.3 Faults

No major faults are recognized within the mélange terrane, possibly due to camouflaging by the inherent chaos. Few faults occur in the surrounding lithologies in the field area, though the Reach Fault, which defines the southern boundary of the Exploits Zone in this region, cuts across the southeast corner of the field area (fig. 2). This section of the Reach Fault is characterized by tectonic slivers of Silurian Wigwam sandstone (Williams, 1967) that approach a kilometer in length and are internally contorted. Associated with these slivers are massive, silicic shear zones exposed on Seal Rock in Burnt Bay and on the coast just south of Emily Cove. The only age constraint on the Reach Fault is that it must post date the Silurian Wigwam sandstone.

Locally the Reach Fault is disturbed by later, north-south trending faults such as the Hales Fault (Kay, 1975), that offsets the Reach Fault to the south for an unknown distance.

The latest demonstrable movements in the mélange are minor faults that offset Jurassic-Cretaceous lamprophyre dikes (pl. 52) (Strong and Harris, 1974; Helwig, et. al., 1974).

4-6 Times of deformation

The Dunnage Mélange records a long, two phase history of deformation marked first by soft rock, dominantly extensional, deformation followed by hard rock compressional events.

The present character of the mélange is largely attributable to pre-Middle Ordovician soft sediment slumping, a discontinuous deformation. The mélange is envisaged as forming by creep and differential movement of a single sedimentary pile as a result of gravity associated with unstable, progressive uplift of a nearby area. Following mélange formation, these processes continued into the Lower Silurian. The intrusion of quartzofeldspathic porphyries and gabbro into the Dunnage and correlative units accompanied the Ordovician-Silurian soft rock deformation. Other evidence of Ordovician-Silurian tectonic movement is the presence of plutonic pebble conglomerates in the New Bay Formation, the Dunnage, and overlying units, indicating uplift in a source area. Thus the Ordovician-Silurian events in the area mark a discontinuous and non-penetrative deformation. These events are in accordance with the Taconic Orogeny of the Appalachians, but rather than displayed by classical attributes of glaring unconformities or metamorphic events, they are recorded somewhat successively by the sedimentary pile. This suggests that the area was a border land to regions undergoing penetrative deformation (Rodgers, 1971).

The timing of later, penetrative events in the area is uncertain. The two Acadian granodiorite bodies in the area pre-date the regional penetrative cleavage, as supported by cleavage-contact metamorphic mineral relationships and dikelets of the granodiorite effected by the cleavage. The granodiorite may also predate the large scale syncline present in the area, as neither body obviously cross-cuts this structure. This syncline may be related to the penetrative cleavage. The penetrative cleavage is also locally effected by a kinking cleavage and kink bands. These events are presumed to be Devonian and related to Acadian Orogeny, as Carboniferous strata elsewhere in the Exploits Zone are flat lying (Williams et. al., 1972).

The latest movements in the area are recorded by small faults that offset Jurassic-Cretaceous lamporphyre dikes.

V. REGIONAL INTERPRETATION

The Dunnage Mélange is the most prominent single unit in the Central Mobile Belt, and as such, has been an integral part of many regional geologic interpretations. Unfortunately, previous interpretations have been precocious or biased in regards to data concerning the geological relationships of the mélange and nearby terranes. Though this study presents new data pertaining to the local origin of the Dunnage Mélange its regional geological significance remains equivocal.

5-1 Previous interpretations and salient features

With the development and acceptance of the plate tectonic hypothesis, a preponderance of models have relied on the Dunnage Mélange as an integral component in models for the geological evolution of the Newfoundland Appalachians. The mélange has been depicted either as an olistostrome shed from the scarp of a normal fault (Horne, 1969) or as an olistostrome and/or tectonic mélange formed at or near an oceanic trench (Dewey, 1969; Bird and Dewey, 1970; Horne, 1970; Kay, 1970, 1972, 1973, 1975; Dewey and Bird, 1971; Franks and Helwig, 1973; Payne, 1974; Williams and Payne, 1975; Hibbard and Williams, 1975; Williams, 1975; Kennedy, 1975; Williams and Hibbard, 1976). Exclusive of Kennedy (1975), all those interpreting the Dunnage as associated with a trench, suggest westward subduction at the site of the mélange. All workers interpret the Dunnage as forming any time from Late Cambrian to Middle Ordovician.

Interpretations of the age of the mélange are within the age constraints outlined in this study, but in general, explanations of the significance of the mélange are not well substantiated. The superficial aspect of most of the previous tectonic models can be attributed to the lack of data or neglect of important observations. The following characteristics of the mélange must be accounted for in any regional synthesis; 1) the components of the mélange and their provenance, 2) the stratigraphic position of the mélange, 3) the mélange as being a locus of intrusions, and 4) its apparent synchroneity with other Newfoundland mélanges.

Consideration of these points yields an interpretation that is bifocal in nature, i.e. the Dunnage can be interpreted as forming in response to geological events to the west or to activity on both the east and west flanks of the Central Mobile Belt.

Though its regional significance remains enigmatic, analysis of these observations allows the portrayal of the Dunnage in a much more realistic manner than has heretofore been attempted.

5-1.1 Components of the Dunnage Mélange

Constituent blocks of the Dunnage Mélange, almost without exception, can be linked to the middle Exploits Group. When compared with subduction related melanges, the Dunnage conspicuously lacks blueschist metamorphism and ophiolitic components, signifying that the Dunnage was not formed in or immediately above a subduction zone.

Worldwide occurrence of mélanges is well documented in the literature (e.g. Greenly, 1919; Doreen, 1951; Bailey and McCallien, 1953, 1963; Renz et. al., 1955; Bird, 1963; Derighi and Cortesini, 1963; Page, 1963; Audley-Charles, 1965; Stevens, 1966; Bruckner, 1966a, b, 1975; Zen, 1967; Hsu, 1968, 1971; Temple, 1968; Abbate et. al., 1970; Abbate and Sagri, 1970; Ernst, 1970; Davies, 1971; Dimitrijevic and Dimitrijevic, 1973; Elter and Trevisan, 1973; Hamilton, 1973; Audley-Charles and Milsom, 1974; Blake and Jones, 1974; Cowan, 1974; Fitch and

and Hamilton, 1974; Gansser, 1974; Maxwell, 1974; Sokolov, 1974; and Wood, 1974). A cursory review of this partial list reveals that mélanges can be subdivided on the basis of constituent blocks which have a direct correspondence to the genesis of the mélange. Thus ophiolitic and ophiolite associated mélanges are related to tectonism of ocean floor, whereas nonophiolitic mélanges reflect tectonism and mass movement in a variety of terranes.

Ophiolitic mélanges are characterized by ophiolitic and non-ophiolitic fragments mixed in a sedimentary or serpentinite matrix (Gansser, 1974). The largest and most intensively investigated is the Franciscan of California (most recently, Hsu, 1968, 1971; Cowan, 1974; Maxwell, 1974; Blake and Jones, 1974). It essentially consists of Jurassic-Eocene greywackes, siltstones, and conglomerates which are chaotically deformed and mixed with scraps of ocean floor and blue-schist blocks. Blueschist knockers indicate high P/T conditions, implying that they have been exhumed from great depths within a sub-duction zone (Ernst, 1970). To the east, the mélange is in tectonic juxtaposition with a thick sequence of clastic sediments resting on ocean floor, the Great Valley sequence. Similar mélanges have been reported in Britain (Greenly, 1919; Wood, 1974) and more recent examples in the South Pacific (Hamilton, 1973). These mélanges have all been interpreted as subduction mélanges based primarily on the presence of blueschists and ophiolites and on regional position, i.e. steeply dipping imbricate zones in tectonic contact with thick clastic sequences.

Gansser (1974), who reviewed ophiolitic mélanges of the Middle East and the Himalayas, notes their close association with ophiolite belts, and proposes that these zones mark major sutures along which obduction of ocean floor onto continental crust has occurred. Unlike mélanges solely attributed to subduction, blueschist blocks are not strikingly apparent in obduction related mélanges. This suggests that obducted ophiolitic mélanges signify shallower depths of the subduction zone (down which continental crust is partially consumed, in this case), than mélanges containing conspicuous blueschist blocks. Supposed obduction mélanges also occur generally in more horizontal dispositions than those interpreted as strictly subduction mélanges.

Previous workers in the Dunnage Mélange have neglected the salient feature that the mélange is void of blueschist blocks and ophiolitic components, nor is it immediately associated with any ophiolite body. Kay (1975) has suggested that a manganiferous sedimentary succession, structurally underlying the mélange at Campbellton, may represent pelagic sediments deposited on oceanic crust. This suggestion is not well substantiated as an ophiolite suite is yet to be revealed in the area. Blocks in the Dunnage represent the slumped correlatives of the middle Exploits Group. Thus it is evident on the basis of constituent blocks that the Dunnage does not conform with subduction or obduction type mélanges and must be considered as forming elsewhere other than in a subduction zone.

5-1.2 The stratigraphic position of the Dunnage Mélange

It has been established in this study that the Dunnage Mélange is a depositional unit that occupies a consistent stratigraphic position at the base of the northeast part of the Exploits Zone, as contends Horne (1969, 1970). This fact alone precludes the Dunnage as having formed as a tectonic mélange within a subduction zone or accretionary prism.

The mélange is the chaotic equivalent of part of the Exploits Group which is directly followed by black shale deposition marking a Caradocian interlude in tectonic activity. The shales are overlain by a coarsening upwards flysch sequence and distinct Silurian sandstones and volcanics. Immediately to the west, the Notre Dame Zone contains slightly older rocks on the whole, than those of the Exploits Zone. The lithologies are dominantly basic volcanic rocks of the Lushs Bight Supergroup that locally overlie ophiolites, as exposed at Betts Cove. All recent workers within the Lushs Bight terrane unanimously interpret these volcanics as representing a Lower Ordovician volcanic arc built on ocean floor (Horne, 1969, 1970; Mitchell and Reading, 1971; Strong, 1973; Kean, 1973; Strong and Payne, 1973; Payne, 1974; Williams and Payne, 1975; Strong and Kean, 1975; Strong, in press).

Lushs Bight sedimentary sections are reminiscent of volcanic-sedimentary sequences of the Exploits Group, such that Horne and Helwig (1969) postulated that the Lushs Bight terranes, at least in part, contemporaneous with the Exploits Group. Volcanic lithologies become increasingly volcaniclastic from the Notre Dame Zone into the Exploits Group.

In light of these facts, the Dunnage Mélange and partially equivalent Exploits Group are situated on the east flank of the Lower Ordovician Lushs Bight island arc (Horne, 1970; Helwig and Franks, 1973). This positioning and the chaotic nature of the mélange has led to its interpretation as marking a Lower Ordovician subduction zone. All previous workers, with the exception of Horne (1969) have neglected the sedimentary contacts of the mélange with surrounding units.

The general form of present day island arc systems has been investigated in detail by many workers (e.g. Mitchell and Reading, 1971; Karig, 1971, 1972, 1974; Dickinson, 1974a, b; and Hamilton, 1974). Typical island arc morphology consists of an active arc flanked by a rear arc basin and a forward subduction zone with an accompanying accretionary prism. The accretionary wedge consists of an arc-trench gap basin with a thick clastic sequence, conformable overlapping with arc volcanics, but in tectonic contact with accreted slabs of subduction melanges and scraps of ocean floor (Dickinson, 1971; Scholl and Marlow, 1974; Seely et. al., 1974; Karig and Syarman, 1975). This tectonic relationship between arc-trench gap sediments and accretionary subduction zone mélanges seems incongruous with the geological situation of the middle Exploits Group and the Dunnage Mélange as described above, thus invalidating any interpretation of the Dunnage as a subduction zone phenomenon.

The conformable interdigitation between the Dunnage Mélange and Exploits Group signifies that they were deposited either within a rear arc basin or an arc-trench gap. Dickinson (1974b) notes that the most important factor in determining the paleogeography of an ancient island is the regional contrast of facies. Thus similar sedimentary basins that form peripheral to the arc can best be distinguished by their association with other elements of the arc system. Unfortunately, geological resolution of the whole Central Mobile Belt is not sharp enough at present to delineate arc system features other than the volcanic chain, itself. The exact paleogeographic situation of the Dunnage therefore remains ambiguous.

5-1.3 <u>The Dunnage Mélange as a locus of intrusions</u>

Quartzofeldspathic and gabbroic intrusions that are localized in the Dunnage Mélange, as well as in the partially correlative New Bay Formation, are essentially coeval with mélange formation and thus the two are probably genetically related. Any interpretation of the mélange formation must also account for the origin of these intrusions.

To date, no such intrusions have been reported from mélanges formed in zones of subduction or obduction. This, too, can be taken as evidence negating such an origin for the Dunnage Mélange.

5-1.4 Apparent synchroneity of Newfoundland mélanges

The very nature and regional setting of mélanges in Newfoundland indicate that these units record cataclysmic events, thus they are of major importance in regional geological interpretation. To quote Williams et. al. (1974) "Their distinctive character suggests that they conceal an important adjunct to the geological interpretation of Central Newfoundland.". The Dunnage Mélange is centrally located between two other mélange zones which occur in two distinct tectonic settings; one between and beneath thrust assemblages of the western platform, and the other flanking the less deformed Central Mobile Belt to the east (fig. 10). The formation of these mélanges appears to be synchronous with that of the Dunnage, suggesting an Ordovician event of grand scale.

Mélanges associated with allocthonous sequences on the Paleozoic carbonate bank of the western platform are extensive but thin and they separate structural slices. An ophiolitic mélange, the Milan Arm (Williams, 1975), forms a distinct sheet within the Hare Bay Allochthon and contains amphibolite, ultramafic rocks and pyroxenite, as well as normal sedimentary-volcanic blocks, all in a black shale matrix. Other mélanges at the bases of the upper mafic and ultramafic thrust slices are marked by ophiolite blocks in a serpentinite matrix. All of these

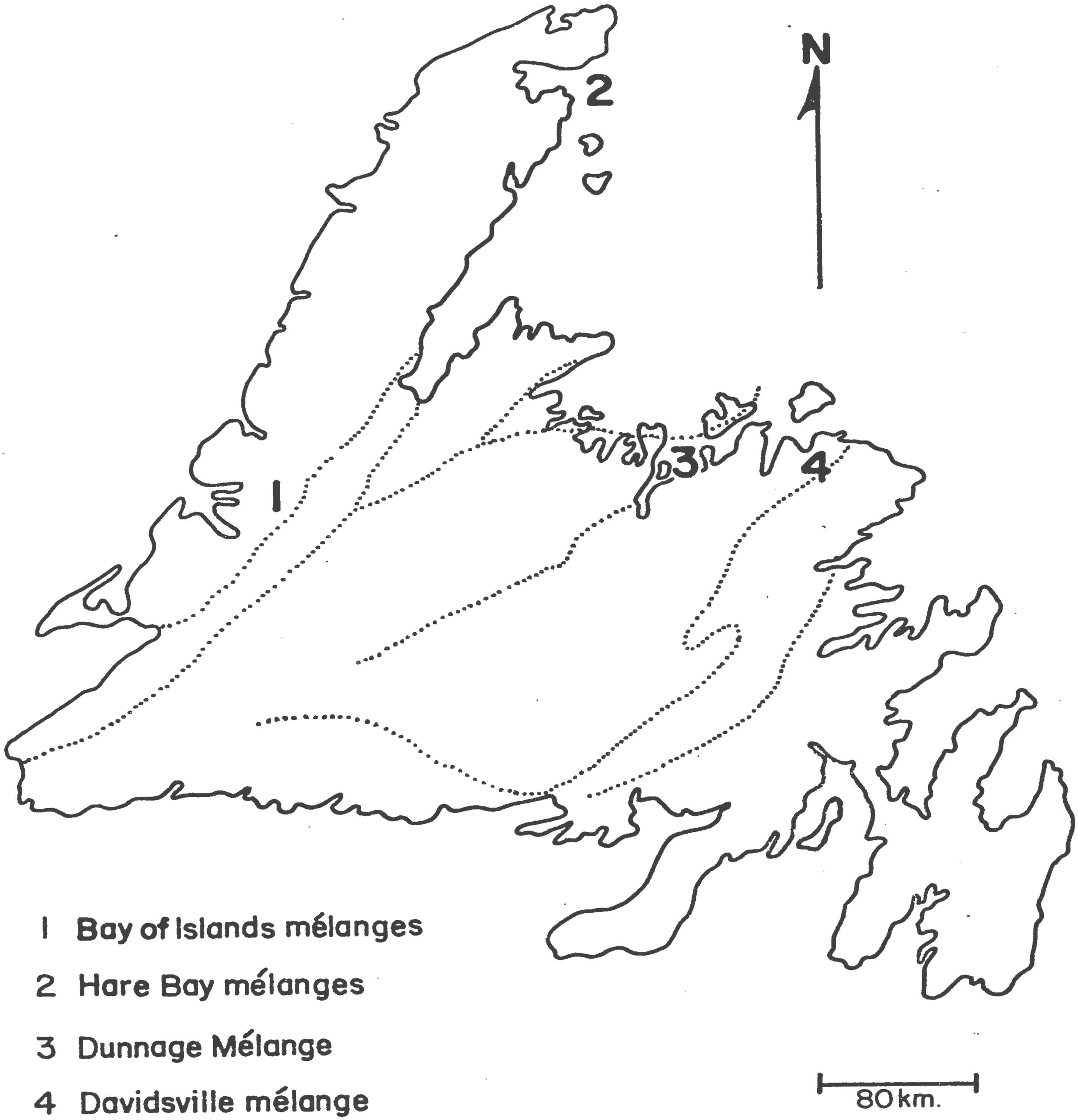


Figure 10: The distribution of Newfoundland Mélanges

mélanges are interpreted to mark zones of movement associated with emplacement of the thrust slices, which were emplaced by Lower Caradocian time (Rogers, 1965). Slice emplacement is generally believed to have occurred along a Lower Ordovician obduction zone where the North American continental shelf underthrust ocean floor to the east (Stevens et. al., 1974), the mélanges have traditionally been interpreted as mass wastage bodies in front of the moving, obducted klippe, and partially entrapped between individual slices (Stevens, 1966; Bruckner, 1966, 1975), though recently Stevens (pers, comm., 1975) proposed that these mélanges may have formed tectonically within a subduction zone where continental crust was being consumed. With isostatic readjustment of the more buoyant continental crust, these assemblages were obducted and are now stranded upon the continental margin.

Flanking the Dunnage to the east, the Davidsville mélange is also the easternmost unit in the Central Mobile Belt and forms the base of the Middle Ordovician Davidsville Group in many places. It contains blocks of greywacke, dolomite and mafic volcanics, but also includes large rafts of metamorphic tectonites near its base, blocks of serpentinite, ultramafic rocks and gabbro (Uzuakpunwa, 1974). The large metamorphic blocks resemble lithologies of the immediately easterly Gander Group, thus leading Kennedy and McGonigal (1972) and Kennedy (1975) to interpret the mélange as representing a gravity slide. Studies in this area are far from conclusive, and ultramafic bodies in the mélange terrane are suggestive of an ophiolitic mélange. The mélange underlies a sequence of sediments including graptolite bearing grey shales of Caradocian age, thus the mélange is Caradocian or older unless the mélange marks a tectonic slide, whereby it could be much younger.

Based on the present evidence it appears extremely coincidental that all of these unique mélanges in Newfoundland appear to be of the same general age, i.e., Lower to Middle Ordovician. The seeming synchroneity of formation of these bodies infers that they record a single, possibly progressive catastrophic event which had broad reaching effects, from the western carbonate platform across to the east edge of the Central Mobile Belt. Considering generally accepted and substantiated hypotheses of tectonic events in Newfoundland, space and time relationships suggest that this event was synchronous with the final stages of obduction of the allochthonous ophiolites and mélanges of western Newfoundland. Similarly, as the slices are pictured to slide westerly off an isostatically adjusting, rising welt, gravity may have caused massive slumping of the precariously positioned Exploits Group on the east side of this welt, thus depositing the Dunnage Mélange. Localization of intrusions within the Dunnage may be a result of isostatic rebound and tensional tectonics. A ubiquitous blanket of black and grey shale marks a lull after the storm and a possible change in tectonic regime. Early in his investigation of the Dunnage, Marshall Kay intuitively proposed this very idea (1966, p. 591), "If the thrust sheets of western Newfoundland glided off a welt in western Burlington Peninsula, there should be similar but opposite structures to the east."

The Davidsville mélange may record the far reaching effects of this uplift, though review of reconnaissance work in this area demands the entertainment of the hypothesis that a separate event was taking place in the eastern Central Mobile Belt.

The map pattern of the Central Mobile Belt suggests that the Dunnage Mélange and the Davidsville mélange may be continuous in subsurface, as they form parallel belts which are structurally separated by the Reach Fault and a sequence of younger Ordovician and Silurian rocks. However, two features of the Davidsville mélange refute continuity with the Dunnage; 1) the content of the mélange, and 2) the possible provenance of its components.

Unlike the Dunnage Mélange, the Davidsville mélange contains ultramafic blocks and gabbro, thus it is ophiolitic in nature. The Gander River ultramafic belt, in places forms the boundary between the Davidsville mélange and the polyphase deformed Gander Group to the east. Uzuakpunwa (1974) has interpreted some of these larger bodies as being incorporated in the mélange. Also rafts of metamorphic tectonites similar to Gander Group lithologies occur in this melange. The Dunnage is void of ultramafic blocks and metamorphic tectonites.

Based on lithologic similarities and stratigraphic relationships, the Dunnage Mélange appears to have originated from lithologies to the west and possibly the north. In contrast, Gander Group type lithologies within the Davidsville have led Kennedy and McGonigal (1972) to infer the provenance of this mélange as being to the east. Thus, source areas for the two mélanges suggest opposing directions of transport for constituent blocks.

Therefore, the position of the Davidsville mélange abutting against the polyphase deformed Gander Group, its easterly inferred provenance, and possible ophiolitic associates suggest that this mélange is associated with a separate event on the eastern margin of the Central Mobile Belt, that possibly occurred synchronously with formation of the Dunnage and obduction of ophiolites to the west. It is also possible that the Davidsville mélange marks the juxtaposition of contrasting basements, as the Gander Group is sialic in nature, while the Exploits and Botwood Zones may have simatic basement as suggested by relationships within the Notre Dame Zone.

Events believed to be analogous with obduction in Newfoundland are also recorded elsewhere in the Appalachians (Williams and Stevens, 1974; Rodgers, 1971) by comparable allochthonous sequences in Quebec, New York and Vermont, and Pennsylvania. These have been termed generally as Taconic events (Rodgers, 1971). South of Newfoundland, lithologies similar to the Dunnage are unknown, though in Virginia, James Run volcanics (Higgins, 1972) appear to occupy a time and space situation in the system similar to that of the Exploits Group and Lushs Bight Supergroup. Occurrence of similar orogenic events and some analogous lithologies suggest that the zone of plate convergence proposed for Newfoundland is represented in other parts of the Appalachian Mountain chain, and it may thus be a possible reference feature for further correlation within the system.

Tectonic events responsible for the formation of the Davidsville mélange are not substantiated elsewhere in the Appalachians at this time.

5-2 Summary

The conformable sedimentary contacts and stratigraphic position, the lack of blueschist, ophiolite detritus or associated ophiolites, and localization of coeval intrusions all indicate that the Dunnage Mélange did not form in a subduction zone or accretionary prism.

The Dunnage was deposited either in a rear arc basin, an arc-trench gap, or a paleogeographic terrane which may have served as both of these parts of an island arc system. The depositional model depends on the interpretation of other regional geologic elements, particularly other mélange zones. If based solely on generally accepted models of the Newfoundland Appalachians, the Dunnage may have formed in a back arc environment in response to obduction of ophiolites in western Newfoundland during the Lower Middle Ordovician. If observations focussed on the Davidsville mélange, which are not enhanced or substantiated other than by reconnaissance studies, are considered, Middle Ordovician tectonic activity to the east of the Dunnage Mélange is implied. Thus the search for the cause of the Dunnage Mélange is bifocal in nature, depending on the scope of geological knowledge considered.

The Dunnage Mélange and similar deposits in Newfoundland appear to be genetically linked, recording a climax during Taconic orogenesis. In Newfoundland, this period of mobilization may have included penetrative deformational events on both sides of the Central Mobile Belt, causing instability and formation of the Dunnage Mélange in the central region. Southerly analogs comparable to the Dunnage Mélange and Davidsville mélange are unknown. These striking deposits record an event in Appalachian history what must have been a truly spectacular incident.

BIBLIOGRAPHY

ABBATE, E., BORTOLOTTI, V., and PASSERINI, P., 1970. Olistostromes an olistoliths, Sed. Geol., 4; p. 521-557.

__________, and SAGRI,M., 1970. The eugeosynclinal sequences, Sed. Geol., 4; p. 251-340.

AGER, D.V., 1973. The Nature of the Stratigraphical Record, Macmillan, London, 114p.

AUDLEY-CHARLES, M.G., 1965. A Miocene gravity slide deposit from Eastern Timor, Geol. Mag., v. 102, no. 3; p. 267-276.

__________, and MILSOM, J.S., 1974. Comment on 'Plate convergence, transcurrent faults and internal deformation adjacent to Southeast Asia and the Western Pacific', Jour. Geophys. Res., v. 79, no. 32; p. 4980-4981.

BAILEY, E.B., and McCALLIEN, W.J., 1953. Serpentine lavas, the Ankara mélange and the Anatolian thrust, Trans. Roy. Soc. Edin., v. 57, pt. 2; p. 403-442.

__________, 1963. Liguria nappe: Northern Apennines, Trans. Roy. Soc. Edin., v. 65, no. 13; p. 315-333.

BERGSTRÖM, S.M., RIVA, J., and KAY, M., 1974. Significance of conodonts, graptolites, and shelly faunas from the Ordovician of western and north-central Newfoundland, Can. Jour. Earth Sci., v. 11, no. 12; p. 1625-1660.

BERKLAND, J.O., RAYMOND, L.A., KRAMER, J.C., MOORES, E.M., O'DAY, M., 1972. What is Franciscan? Bull. AAPG, v. 56; p. 2295-2302.

BIRD, J.M., 1969. Middle Ordovician gravity sliding-Taconic Region, in AAPG mem. 12; p. 670-686.

__________, and DEWEY, J.F., 1970. Lithosphere plate-continental margin tectonics and the evolution of the Appalachian Orogen, GSA Bull., v. 81; p. 1031-1060.

BLAKE, M.C., Jr., and JONES, D.L., 1974. Origin of Franciscan melanges in Northern California, Soc. Ec. Paleon. and Min. spcl. pub. no. 19; p. 345-357.

BOSWELL, P.G.H., 1961. Muddy Sediments, Heffner and Sons, Ltd., Cambridge, 140p.

BRÜCKNER, W.D., 1966. Zones of chaotic structure in Newfoundland, Eastern Canada. Geol. and Min. Ass. of Can., Tech. Prog., Halifax, Nova Scotia; p. 8-9.

__________, 1966. Stratigraphy and Structure of West-Central Newfoundland, in Guidebook, Geology of Parts of Atlantic Provinces, GAC-MAC ann. mtg., Halifax; p. 137-155.

__________, 1973. Young post-glacial sea level changes in Newfoundland, Eastern Canada, Results of a reconnaissance study, Ninth Congr. Int. Union Quat. Res., Christchurch N.Z. abs.; p. 47-48.

__________, 1975. Origin of "Zones of chaotic structure" in certain orogenic belts, Intern. Congr. of Sedmntlgy., Nice.

CAREY, S.W., 1963. Syntaphral tectonics, in Syntaphral Tectonics and Diagenesis, A Symposium, Geol. Dept., Univ. of Tasmania, Hobart; p. B1-B7.

CARLISLE, D., 1963. Pillow breccias and their aquagene tuffs, Quadra Island, B.C., Jour. of Geol., v.71; p. 48-71.

CLOOS, E., 1964. Wedging, bedding plane slips and gravity tectonics in the Appalachians, in Tectonics of the Southern Appalachians, VPI Dept. of Geolog. Sci. mem. 1; p. 63-70.

COWAN, D.S., 1974. Deformation and metamorphism of the Franciscan subduction zone complex northwest of Pacheco Pass, Ca., GSA bull., v. 85; p. 1623-1634.

CROWELL, J.C., 1957. Origin of pebbly mudstones, GSA bull., v. 85; p. 993-1010.

DAVIESS, S.M., 1971. Barbados, a major submarine gravity slide, GSA bull., v. 82; p. 2593-2602.

DeRIGHI, R., and CORTESINI, A., 1964. Gravity tectonics in foothills structure belt of southeast Turkey, AAPG bull., v. 48, no. 12; p. 1911-1937.

DENNIS, J.G., 1972. Structural Geology, The Ronald Press Co., N.Y., 532p.

DEWEY, J.F., 1969. Evolution of the Appalachian/Caledonian Orogen, Nature, v. 222; p. 124-129.

__________, and BIRD, J.M., 1970. Mountain belts and the new global tectonics, Jour. Geophys. Res., v. 75, no. 14; p. 2625-2647.

DICKINSON, W.R., 1971. Clastic sedimentary sequences deposited in shelf, slope, and trough settings between magmatic arcs and associated trenches, Pac. Geol., v. 3; p. 15-30.

__________, 1974a. Sedimentation within and beside ancient and modern magmatic arcs. Soc. Econ. Paleon. and Min. spcl. pub. no. 19; p. 230-239.

__________, 1974b. Plate tectonics and sedimentation, Soc. Econ. Paleon. and Min. spcl. pub. no. 22; p. 1-27.

DIMITRIJEVIC, M.D., and DIMITRIJEVIC, M.C., 1973. Olistostrome mélange in the Yugoslavian Dinarides and Late Mesozoic plate tectonics, Jour. Geol., v. 81; p. 328-340.

DORREEN, J.M., 1951. Rubble bedding and graded bedding in Talara formation of northwestern Peru, AAPG bull., v. 35, no. 8; p. 1829-1849.

DOTT, R.H., 1963. Dynamics of subaqueous gravity depositional processes, AAPG bull., v. 47, no. 1; p. 104-128.

ELLISTON, J.N., 1963a. Gravitational sediment movement in the Warramunga Geosyncline, in Syntaphral Tectonics, A Symposium, Univ. Tasmania, Hobart, p. C1-C17.

__________, 1963b. Sediments of the Warramunga Geosyncline, in Syntaphral Tectonics, Univ. Tasmania, Hobart, p. L1-L45.

ELTER, P., and TREVISAN, L., 1973. Olistostromes in the tectonic evolution of the Northern Apennines, in Gravity and Tectonics, DeLong and Schotten, eds., John Wylie and Sons, N.Y.; p. 175-188.

ERNST, W.G., 1970. Tectonic contact between the Franciscan mélange and the Great Valley sequence - crustal expression of a late Mesozoic Benioff zone, Jour. Geophys. Res., v. 75, p. 886-901.

FITCH, T.J., and HAMILTON, W., 1974. Reply to Audley-Charles and Milsom, Jour. Geophys. Res., v. 79, no. 32; p. 4982-4985.

FRANKS, S.G., 1974. Prehnite-pumpellyite facies metamorphism of the New Bay Formation, Exploits Zone, Newfoundland, The Can. Miner., v. 12, pt. 7; p. 456-462.

__________, and HELWIG, J., 1973. Petrology and Sedimentation of Early Paleozoic island-arc deposits, Newfoundland, abs., AAPG bull., v. 57, p. 779.

GANSSER, A., 1974. The ophiolitic mélange, a world-wide problem on Tethyan examples, Eclog. geol. Helv., v. 67/3; p. 479-507.

GREENLY, E., 1919. The Geology of Angelsey, Great Britain Geol. Sur. mem., 980p.

HAMILTON, W., 1973. Tectonics of the Indonesian region, Geol. Soc. Malay, bull., v. 6; p. 3-10.

__________, 1974. Map of sedimentary basins of the Indonesian region, U.S.G.S., Reston Va., 1:5,000,000, map I-875-B.

HELWIG, J., 1967. Stratigraphy and structural history of the New Bay area, north central Newfoundland., unpub. Ph.D. dissert., Columbia Univ., N.Y.; 211p.

__________, 1969. Redefinition of Exploits Group, Lower Paleozoic, northeast Newfoundland, AAPG mem. 12; p. 408-413.

__________, 1970. Slump folds and early structures, northeast Nfld. Appalachians, Jour. Geol., v. 78; p. 172-187.

__________, ARONSON, J., and DAY, D.S., 1975 A Late Jurassic mafic pluton in Newfoundland, Can. Jour. Ear. Sci., v. 11, no. 9; p. 1314-1319.

__________, and SARPI, E., 1969. Plutonic pebble conglomerates, New World Island, Newfoundland, and history of eugeosynclines, AAPG mem. 12; p. 443-466.

HEYL, G.R., 1935. Geology and mineral deposits of the Bay of Exploits area, Notre Dame Bay, Newfoundland, unpub. Ph.D. dissert., Princeton Univ.; 219p.

__________, 1936. Geology and mineral deposits of the Bay of Exploits area, Newfoundland, Nfld. Dept. Nat. Res. Geol. Soc. bull. 3, 66p.

HIBBARD, J.P., 1976. The Dunnage Mélange, central Newfoundland Appalachians, abs. with prog., NE-SE GSA Sect mtg., in press.

__________, and WILLIAMS, H., 1975. The Dunnage Mélange, northeast Newfoundland, abs. with prog., GAC-MAC annual mtg., Waterloo, Ont.; p.

HIGGINS, M.W., 1972. Age, origin, regional relations, and nomenclature of the Glenarm Series, central Appalachian Piedmont; a reinterpretation, GSA bull., v. 83; p. 989-1026.

HORNE, G.S., 1968. Stratigraphy and structural geology southwestern New World Island area, Newfoundland, unpub. Ph.D. dissert., Columbia Univ., N.Y.; 280p.

__________, 1969. Early Ordovician chaotic deposits in the central volcanic belt of northeastern Newfoundland, GSA bull., v. 80; p. 2451-2464.

__________, 1970. Complex volcanic-sedimentary patterns in the Magog Belt of northeastern Newfoundland, GSA bull. v. 81; p. 1767-1788.

HORNE, G.S. and HELWIG, J., 1969. Ordovician stratigraphy of Notre Dame Bay, Newfoundland, AAPG mem. 12; p. 388-407.

HSÜ, K.S., 1968. Principles of mélanges and their bearing on the Franciscan-Knoxville paradox, GSA bull., v. 79, p. 1063-1074.

__________, 1969. Role of cohesive strength in the mechanics of overthrust faulting and of landsliding, GSA bull., v. 80; p. 927-952.

__________, 1971. Franciscan mélanges as a model for eugeosynclinal sedimentation and underthrusting tectonics, Jour. Geophys. Res., v. 76; p. 1162-1170.

__________, 1974. Mélanges and their distinction from olistostromes, Soc. Econ. Paleon. and Miner, spec. pub. no. 12; p. 321-333.

HUBBERT, M.K. and RUBEY, W.W., 1959. Role of fluid pressure in mechanics of overthrust faulting, part I, GSA bull. v. 70; p. 115-166.

JUKES, J.B., 1842. Excursions in and about Newfoundland during the years 1839-1840, v. 1, 2; London, John Murray, 322p., 354p.

KARIG, D.E., 1971. Origin and development of marginal basins in the western Pacific, Jour. Geophys. REs., v. 76; p. 2542-2561.

__________, 1972. Remnant Arcs, GSA bull., v. 83; p. 1057-1068.

__________, 1974. Evolution of arc systems in the western Pacific, Ann. Rev. of Ear. and Plan. Sci., v. 2; p. 51-75.

__________, and SHARMAN, G.F. III, 1975. Subduction and accretion in trenches, GSA bull., v. 86; p. 377-389.

KAY, M., 1966. Comparison of the Lower Paleozoic volcanic and non-volcanic geosynclinal belts in Nevada and Newfoundland, Bull. Can. Pet. Geol., v. 14, no. 4; p. 579-599.

__________, 1967. Stratigraphy and structure of northeast Newfoundland bearing on drift in the North Atlantic, AAPG bull., v. 14; p. 579-599.

__________, 1970. Flysch and bouldery mudstone in Northeast Newfoundland, GAC spec. pap. no. 7; p. 155-164.

__________, 1972. Dunnage Mélange and Lower Paleozoic deformation in northeast Newfoundland, Int. Geol. Cngr., 24th, sect. 3; p. 122-133.

__________, 1973. Tectonic evolution of Newfoundland, in DeJong and Schotten (eds.), Gravity and Tectonics, John Wiley and Sons, N.Y.; p. 313-326.

__________, 1975. Campbellton sequence, manganiferous beds adjoining the Dunnage mélange, northeastern Newfoundland, GSA bull., v. 86; p. 105-108.

__________, and ELDREDGE, N., 1968. Cambrian trilobites in central Newfoundland volcanic belt, Geol. Mag., v. 105; p. 372-377.

KEAN, B.F., 1973. Geology, stratigraphy and geochemistry of the volcanic rocks of Long Island, Notre Dame Bay, Newfoundland: unpub. M.Sc. thesis, M.U.N.; 154p.

__________, and STRONG, D.F., 1975. Geochemical evolution of an Ordovician island arc of the central Newfoundland Appalachians, Am. Jour. Sci., v. 275; p. 97-118.

KENNAN, P.S., 1972. Some curious garnet clusters from the Garnetiferous Beds of the Leinster Granite aureole, Geol. Mag., v. 109, no. 2; p. 165-170.

KENNEDY, M.J., 1975. Repetitive orogeny in the northeastern Appalachians - new plate models based upon Newfoundland examples, Tectonophys., v. 28; p. 39-87.

__________, and McGONIGAL, M.H., 1972. The Gander Lake and Davidsville Groups of northeastern Newfoundland: New data and geotectonic implications, CJES, v. 9, no. 4; p. 452-459.

KRANCK, E.H., 1952. Geology of Lewisporte-Cottrels Cove-Loon Bay region, unpub. rept. on file GSC.

KLEIST, J.R., 1974. Deformation by soft-sediment extension in the Coastal Belt, Franciscan Complex, Geol., v. 2, no. 10; p. 501-504.

MAXWELL, J.C., 1962. Origin of slaty and fracture cleavage in the Delaware Water Gap area, New Jersey and Pennsylvania, in Engel, A.E.J., James, H.L. and Leonard, B.F. (eds.), Petrologic Studies, a volume to honor A.F. Buddington, GSA; p. 281-312.

__________, 1974. Anatomy of an orogen, GSA bull., v. 85; p. 1195-1204.

MILLER, H.G., and DEUTSCH, E.R., 1973. A gravity survey of eastern Notre Dame Bay, Newfoundland, GSC paper 71-23; p. 389-406.

MILNE, J., 1877. On the rocks of Newfoundland, Geolog. Magazine, II, v. IV; p. 251-262.

MITCHELL, A.H., and READING, H.G., 1971. Evolution of island arcs, Jour. Geol., v. 79; p. 253-284.

MOORE, J.C. and GEIGLE, J.E., 1974. Slaty cleavage, incipient occurrences in the deep sea, Science, v. 183; p. 509-510.

MURRAY, A., and HOWLEY, J.P., 1881. Reports of the Geological Survey of Newfoundland from 1864-1880, Stanford, London; 536p.

OVERSBY, B.S., 1967. Geology of Upper Black Island, Bay of Exploits, Newfoundland, unpub. M.A. thesis, Columbia Univ. N.Y.; 68p.

PAGE, B.M., 1963. Gravity tectonics near Passo Della Cisa, northern Apennines, Italy, GSA bull., v. 74; p. 655-672.

PATRICK, T.O.N., 1956. Comfort Cove, Newfoundland, map with notes, GSC pap. 55-31.

PAYNE, J.G., 1974. The Twillingate Granite and its relationships to surrounding country rocks, unpub. M.Sc. thesis, M.U.N., St. John's, Nfld.; 159p.

PHILLIPS, F.C., 1960. The Use of Stereographic Projection in Structural Geology, Edward Arnold, London; 90p.

RENZ, O.R., LAKEMAN, R., and VAN DE MEULEN, E., 1955. Submarine sliding in western Venezeula, AAPG bull. 39; p. 2053-2067.

RODGERS, J., 1965. Long Point and Clam Bank Formations, western Newfoundland, Can. Geol. Assoc. Proc., v. 16; p. 83-94.

__________, 1971. The Taconic Orogeny, GSA bull. v. 82; p. 1141-1178.

SCHOLL, D.W. and MARLOW, M.S., 1973. The sedimentary sequence in modern Pacific trenches and the deformed circum-Pacific eugeosynclines, Soc. Econ. Paleon. and Miner., spec. pub. no. 19; p. 193-211.

SEELY, D.R., VAIL, P.R., and WALTON, G.G., 1974. Trench slope model, in Burk, C.A. and Drake, C.L., The Geology of Continental Margins, Springer Verlag, Inc.; p. 249-260.

SOKOLOV, S.D., 1974. Tectonic mélange in the Amasiya region, Lesser Caucasus, Acad. of Sci. of U.S.S.R., Geotect., no. 1; p. 35-38.

SPRY, A., 1969. Metamorphic Textures, Pergammon Press, Toronto; 350p.

STEVENS, R.K., 1965. Geology of the Humber Arm, west Newfoundland, unpub. M.Sc. thesis, M.U.N., St. John's, Newfoundland

__________, STRONG, D.F., and KEAN, B.F., 1974. Do some eastern Appalachian ultramafic rocks represent mantle diapirs produced above a subduction zone?, Geol., v. 2, no. 4; p. 175-178.

STRONG, D.F., 1973. Lushs Bight and Roberts Arm Groups of central Newfoundland; possible juxtaposed oceanic and island-arc suites, GSA bull. v. 84; p. 3917-3928.

__________, in press. Volcanic regimes of the Newfoundland Appalachians, GAC spec. pap.

__________, and HARRIS, A., 1974. The Petrology of Mexozoic Alkaline Intrusives of Central Newfoundland, Can. Jour. Ear. Sci., v. 11, no. 9; p. 1208-1219.

__________, and PAYNE, J.G., 1973. Early Paleozoic volcanism and metamorphism of the Moreton's Harbour-Twillingate area, Newfoundland, Can. Jour. Ear. Sci., v. 10, no. 9, p. 1363-1379.

TEMPLE, P.G., 1968. Mechanics of large scale gravity sliding in the Greek Peloponessos, GSA bull., v. 79; p. 687-700.

TWENHOFEL, W.H. 1947. The Silurian of eastern Newfoundland, with some data relating to physiography and Wisconsin glaciations of Newfoundland, AJS, v. 245; p. 65-122.

__________, and SCHROCK, R.R., 1937. Silurian strata of Notre Dame Bay and Exploits Valley, Newfoundland, GSA bull., v. 48; p. 1743-1772.

UZUAKPUNWA, A.B., 1974. Structural studies of the Gander and Davidsville Groups in the Carmanville-Ladle Cove areas, Newfoundland, unpub. M.Sc. thesis, M.U.N.; 136p.

WANLESS, R.K., STEVENS, R.D., LaCHANCE, G.R. and RIMSAITE, R.Y.H., 1965. Age determinations and geological studies, part I - isotopic ages, rept. 5, GSC pap. 64-17.

__________, __________, __________, and EDMOND, C.M., 1967. Age determinations and geological studies, K-Ar ages, rept. 7, GSC pap. 66-17.

WILLIAMS, H., 1963. Twillingate map-area, Newfoundland 2E/10 GSC rept. and map 33-1963, 30p.

__________, 1964a. Botwood, Newfoundland, GSC map 60-1963 with marg. notes.

__________, 1964b. The Appalachians in northeastern Newfoundland, a two sided symmetrical system, Am. Jour. Sci., v. 262; p. 1137-1158.

__________, 1965. Notes on the orogenic history and isotopic ages of Botwood map-area, northeastern Newfoundland; in Age Determinations and geological studies, GSC pap. 64-17, part II; p. 22-25.

__________, 1967. Unpub. mans., Botwood map-area.

__________, 1975. Structural succession nomenclature and interpretation of transported rocks in western Newfoundland, Can. Jour. Ear. Sci., v. 12, no. 11; p. 1874-1894.

__________, and HIBBARD, J.P., 1976. The Dunnage Mélange, Newfoundland, GSC pap.

__________, KENNEDY, M.J., and NEALE, E.R.W., 1970. The Hermitage flexure, the Cabot Fault, and the disappearance of the Newfoundland central mobile belt: GSA bull., v. 81; p. 1563-1568.

__________, __________, and __________, 1972. The Appalachian Structural province, in Tectonic Styles in Canada, Price, R.A. and Douglas, R.J.W., eds., GAC spec. pap. 11, 1973.

__________, 1974. The northeastward termination of the Appalachian Orogen, in Nairn, A.E.M., and Stehli, F.G., eds., The Ocean Basins and Margins, vol. 2, Plenum Pub., N.Y.

__________, and PAYNE, J.G., 1975. The Twillingate Granite and nearby volcanic groups: an island-arc complex in northeast Newfoundland, CJES, v. 12, no. 6; p. 982-995.

__________, and STEVENS, R.K., L974. The ancient continental margin of eastern North America, in Burk, C.A., and Drake, C.L., eds., The Geology of Continental Margins, Springer-Verlag, N.Y.; p. 781-796.

WOOD, D.S., 1974. Ophiolites, mélanges, blueschists, and ignimbrites: Early Caledonian subduction in Wales?, Soc. Econ. Paleon. and Miner. spec. pub. no. 19; p. 334-344.

ZEN, E., 1967. Time and Space Relationships of the Taconic Allochthon and Autochthon, GSA spec. pap. no. 97; 107p.

APPENDIX I

Major Element Chemistry - Basic Pillow Lavas

%	1	2	3	4	5	6
SiO_2	47.0	52.1	46.7	48.1	21.6	49.5
TiO_2	3.01	1.39	2.93	2.73	2.61	1.12
Al_2O_3	13.5	20.20	15.10	12.00	4.95	19.80
FeO	15.00	9.91	10.59	9.73	6.96	9.02
Fe_2O_3	1.82	0.22	2.24	1.01	11.58	0.44
MnO	0.62	0.15	0.29	0.28	0.82	0.17
MgO	7.55	3.31	4.26	9.60	12.30	4.78
CaO	8.31	2.22	7.49	10.78	19.24	2.02
Na_2O	0.66	6.15	4.77	2.25	0.57	5.94
K_2O	0.22	1.12	0.85	1.23	0.77	1.17
P_2O_5	0.32	-	0.42	0.58	6.37	-
L.O.I.	2.92	3.62	4.16	2.29	11.26	5.98
TOTAL	100.93	100.39	99.80	100.58	99.03	99.94

Trace Element Chemistry - Basic Pillow Lavas

ppm						
Zr	146	89	218	271	1331	99
Sr	339	153	178	684	4884	465
Rb	20	45	34	22	35	61
Zn	133	65	736	136	198	76
Cu	23	101	93	20	20	45
Ba	159	187	245	550	845	340
Nb	10	15	35	36	202	8
Ni-Pb	65	120	66	174	62	195
Cr	43	665	77	470	7	877

APPENDIX I (cont'd)

Major Element Chemistry - Basic Pillow Lavas

%	7	8	9	10	11
SiO_2	47.6	54.0	46.2	48.5	51.0
TiO_2	3.33	2.46	0.50	2.04	1.23
Al_2O_3	14.70	12.70	10.80	15.60	17.40
FeO	9.75	12.15	12.40	11.79	7.36
Fe_2O_3	1.53	2.64	0.42	0.78	0.35
MnO	0.15	0.51	0.56	0.23	0.08
MgO	8.42	3.65	13.80	6.71	4.91
CaO	8.40	7.94	7.12	6.30	4.79
Na_2O	3.73	3.00	0.68	3.23	2.90
K_2O	1.36	0.45	0.52	2.23	0.53
P_2O_5	0.60	0.96	0.18	0.37	0.24
L.O.I.	2.08	1.41	6.84	2.27	8.36
TOTAL	100.65	101.87	100.02	100.05	99.15

Trace Element Chemistry - Base Pillow Lavas

ppm					
Zr	157	124	32	129	158
Sr	250	177	80	390	455
Rb	22	19	23	71	26
Zn	97	151	158	125	78
Cu	66	11	8	10	32
Ba	540	317	236	839	502
Nb	22	20	9	17	25
Ni-Pb	260	34	437	82	67
Cr	1054	13	2014	325	73

APPENDIX I (cont'd)

Major Element Chemistry - Manganiferous Nodules

%	1	2
SiO_2	55.8	59.0
TiO_2	0.80	0.54
Al_2O_3	13.5	11.8
FeO	7.68	10.29
Fe_2O_3	1.88	1.47
MnO	14.20	6.80
MgO	1.70	2.20
CaO	1.20	3.50
Na_2O	0.45	0.19
K_2O	1.23	0.65
P_2O_5	.22	.96
L.O.I.	0.57	1.35
TOTAL	99.23	98.75

Trace Elements - Manganiferous Nodules

ppm	1	2
Zr	95	65
Sr	33	61
Rb	64	54
Zn	72	76
Cu	34	102
Ba	178	88
Nb	17	14
Ni-Pb	68	49
Cr	47	32

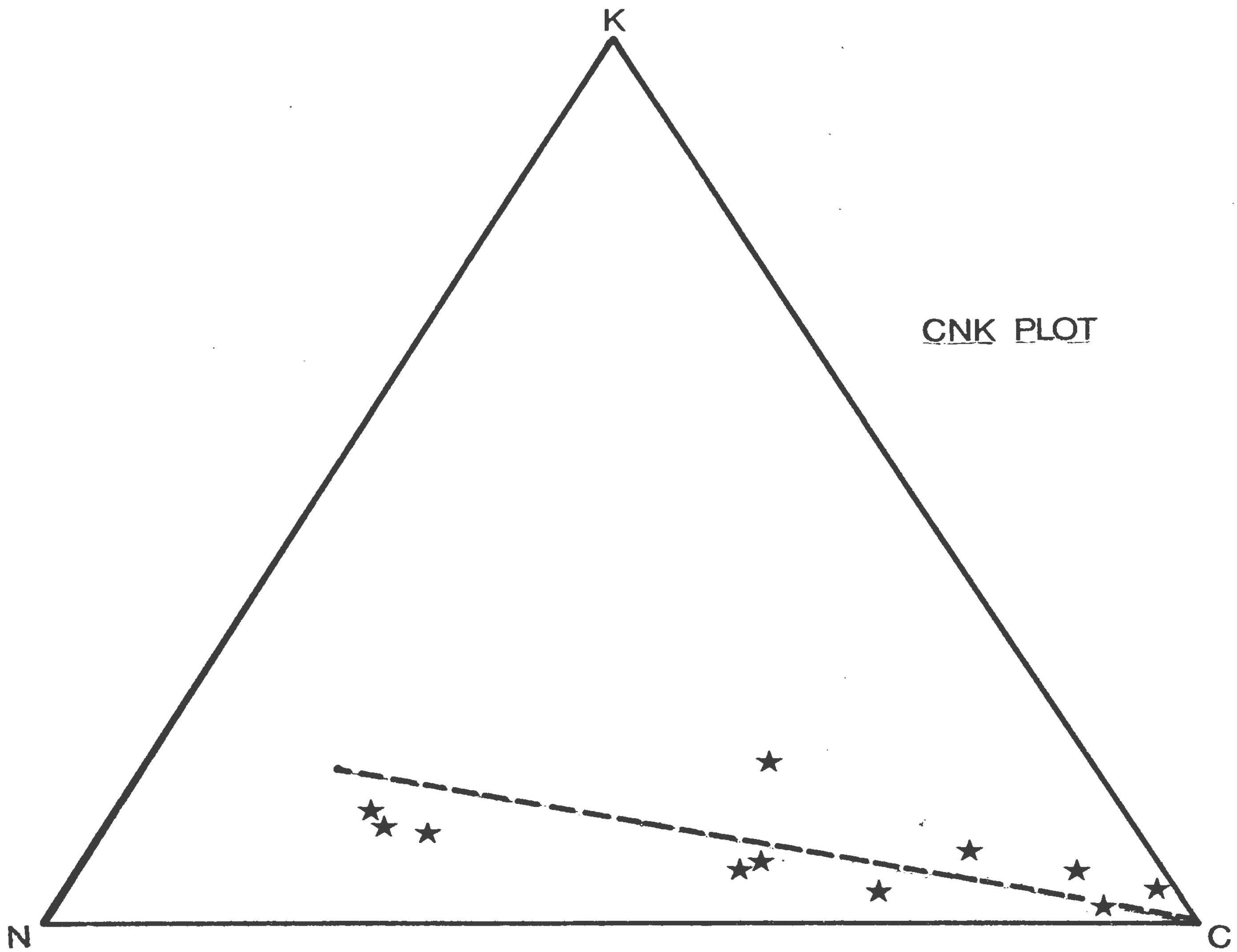


Figure 11: CaO-NaO-K_2O plot of basic pillow lava from the southwest portion of the Dunnage Mélange

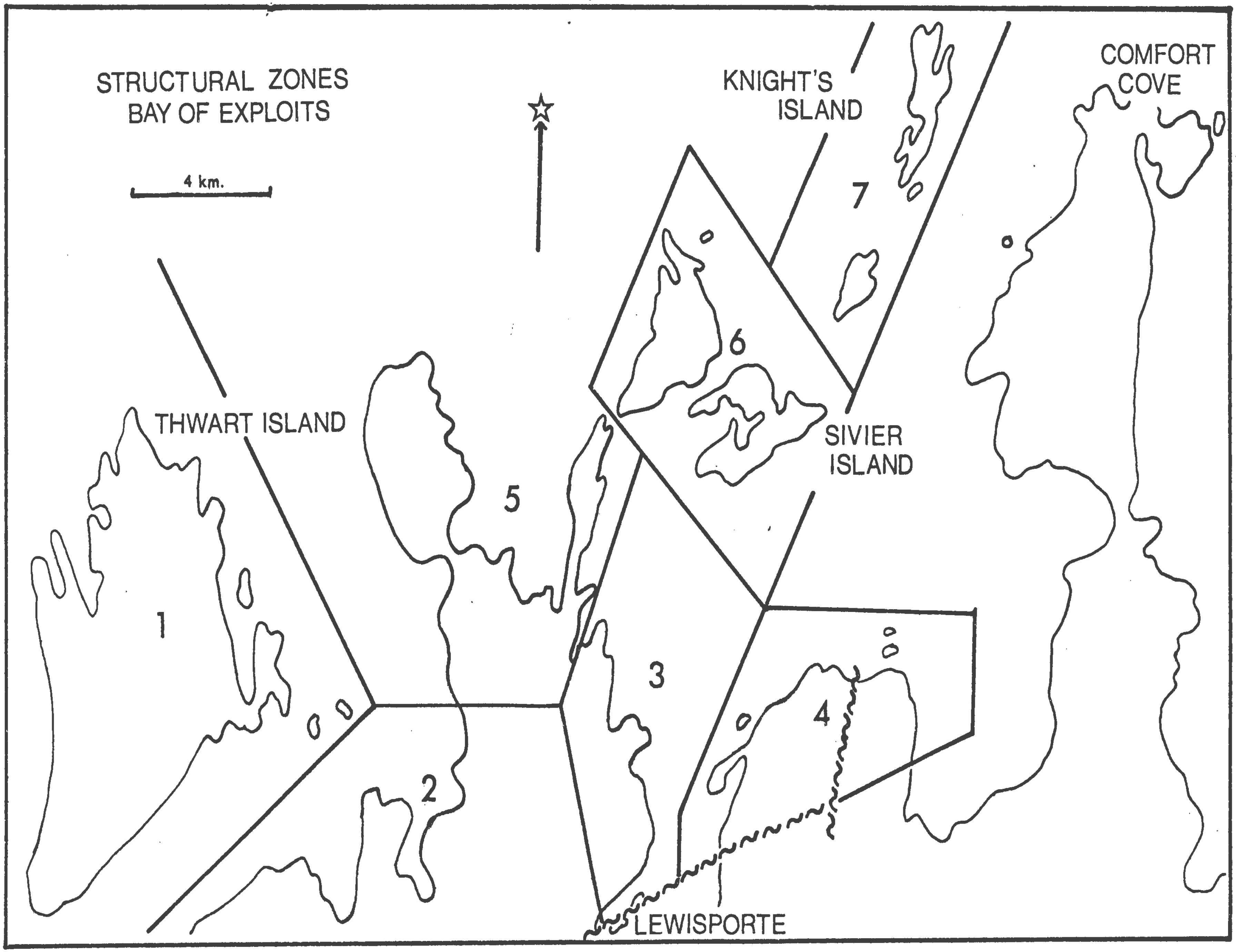


Figure 12: Structural zones, Bay of Exploits

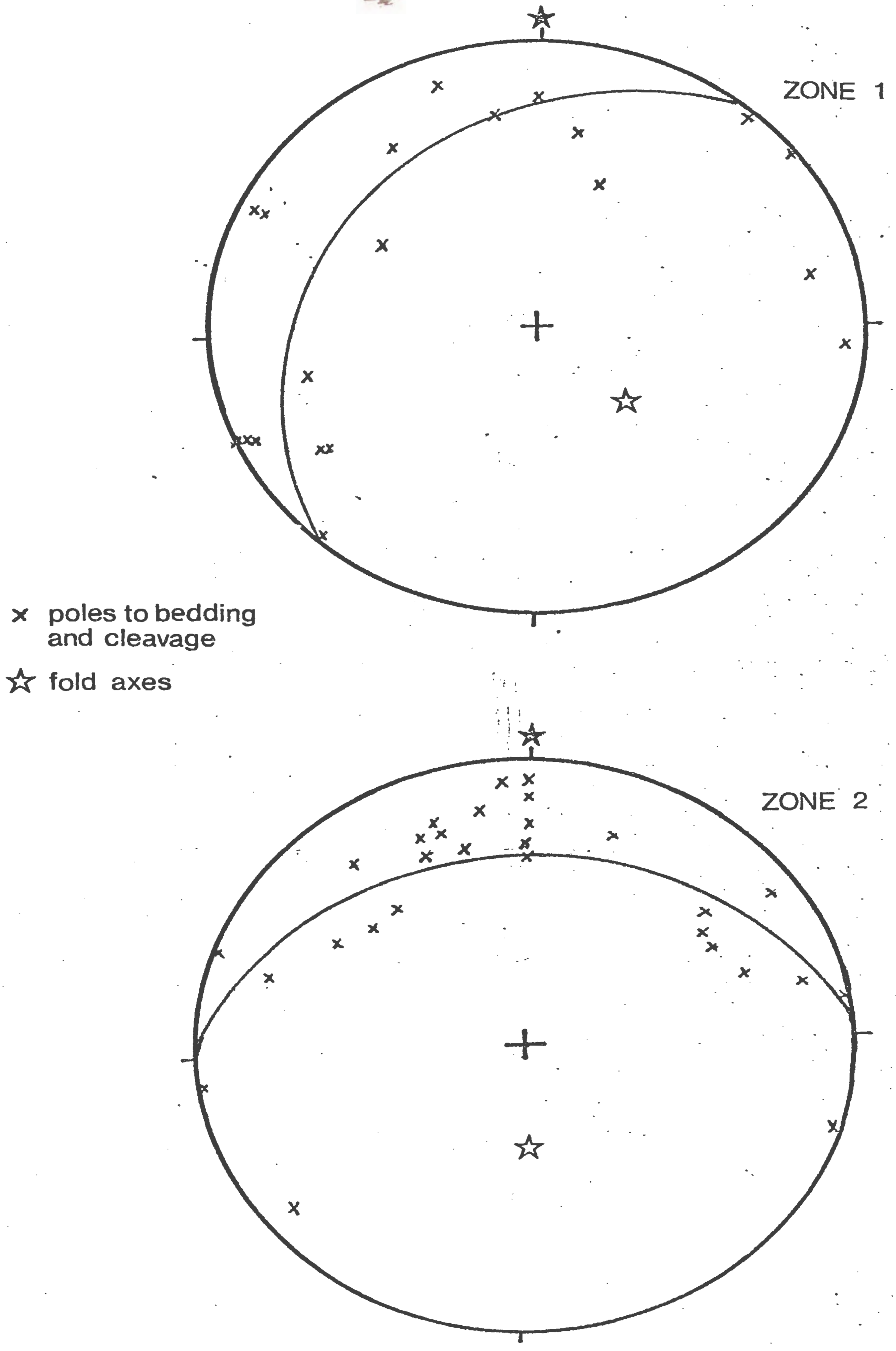


Figure 13: STEREOGRAPHIC PROJECTIONS

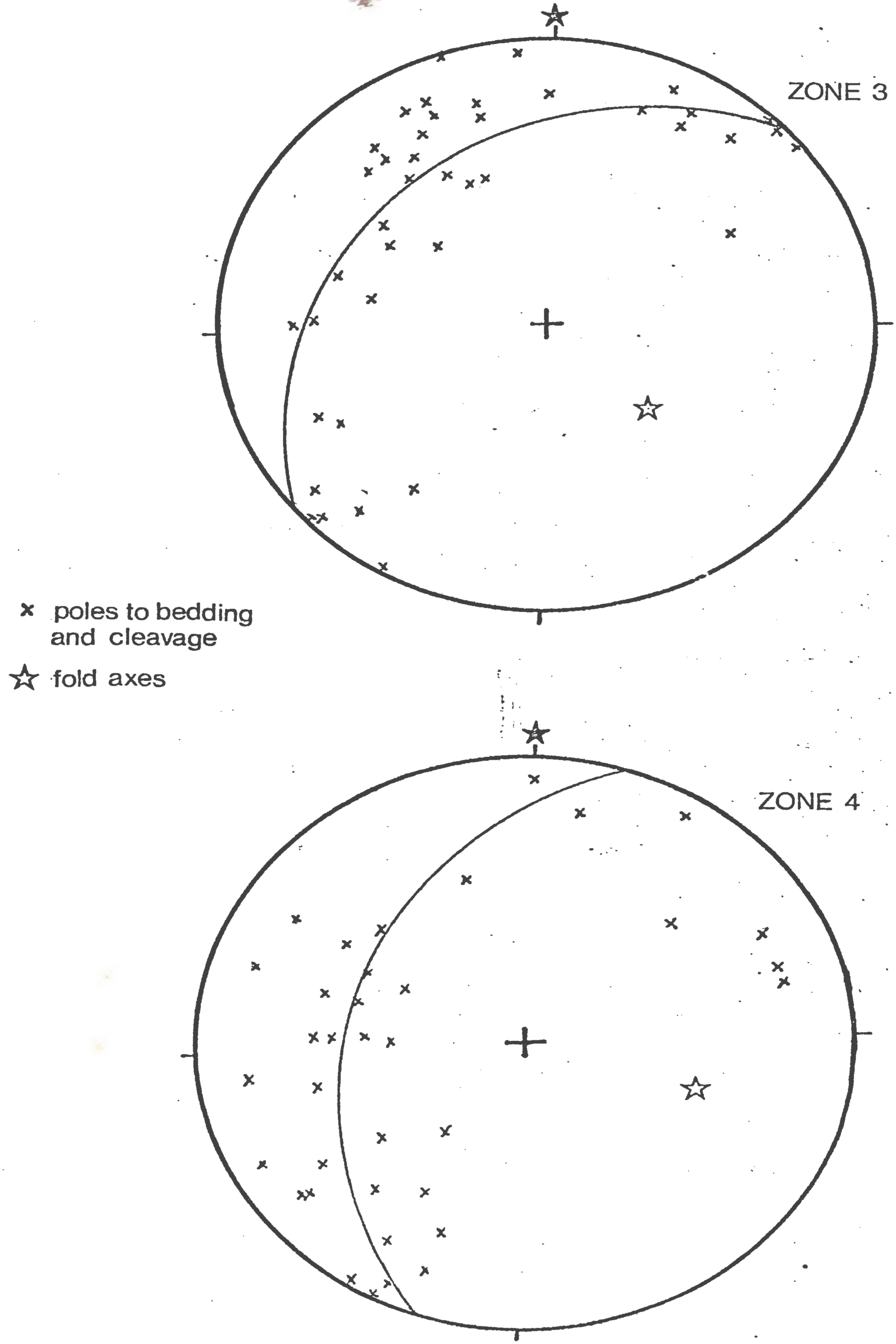


Figure 14: STEREOGRAPHIC PROJECTIONS

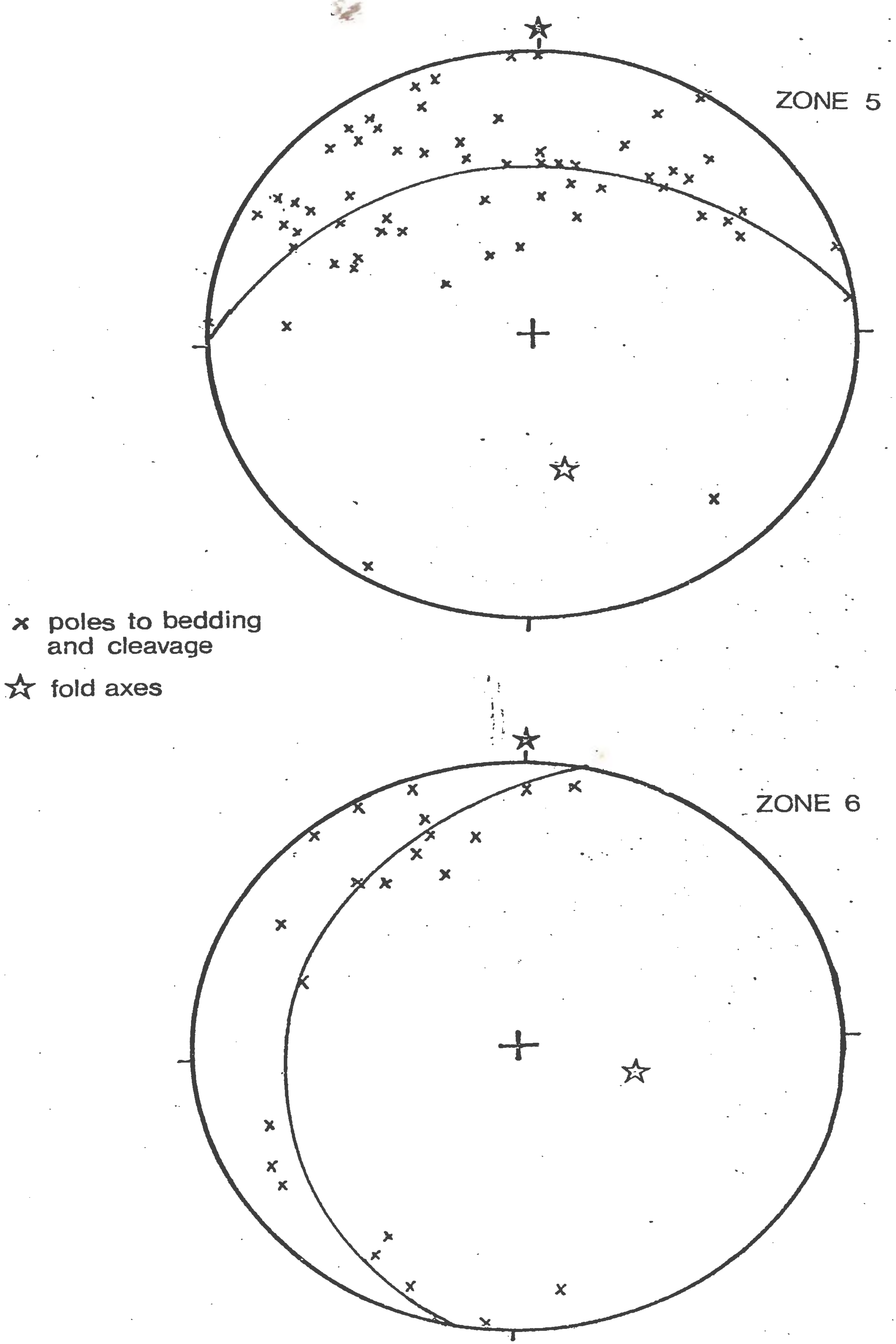
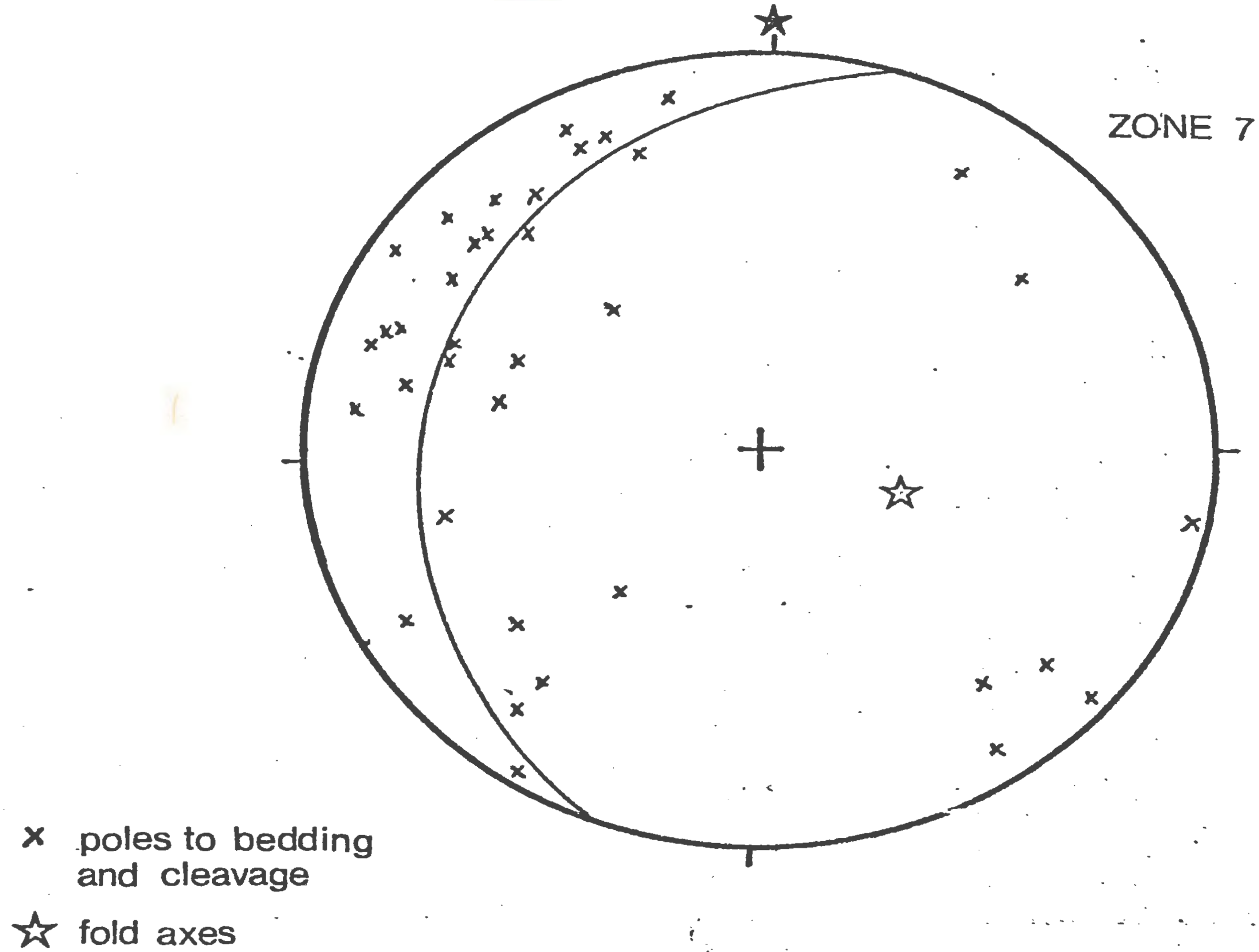


Figure 15: STEREOGRAPHIC PROJECTIONS



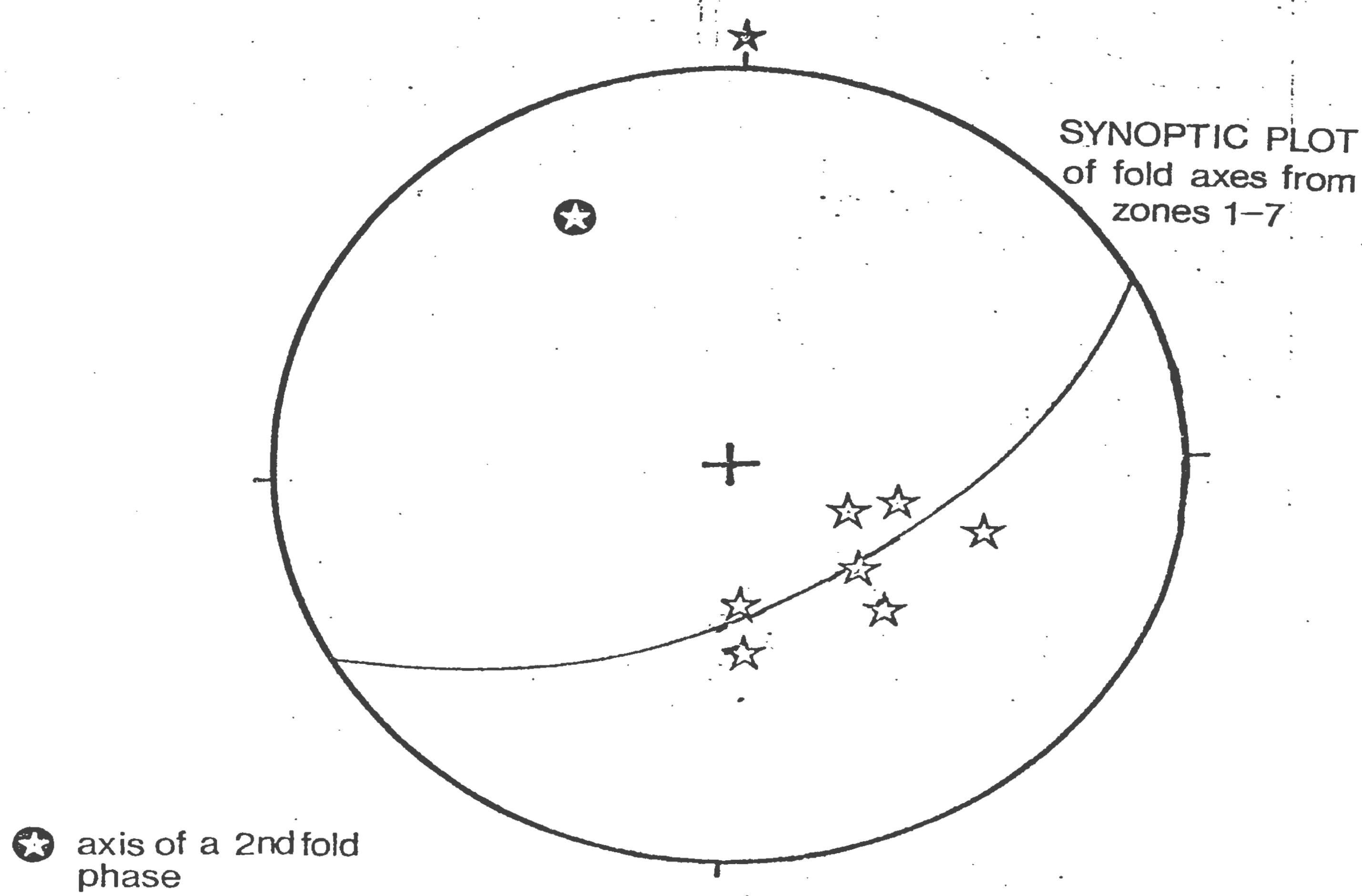


Figure 16: STEREOGRAPHIC PROJECTIONS

"We're not obligated to know everything, now, are we."

Marshall Kay, October 1974

Addendum:

Since the writing of this thesis, another fossil locality has been found in the Dunnage terrane. Two conodont species, Protopanderodus variocostatus (Sweet and Bergström) and Acontiodus sp., s.f., along with a variety of unidentifiable brachiopod fragments and crinoid columnals have been recovered from a carbonate block (S. Stouge, pers. comm., 1976). The block was collected from James Island by the author.

The carbonate block is coarsely recrystallized and contains abundant tuff. The single block was situated in a massive, chaotic, tuffaceous sandstone unit that is overlain by basic volcanic flow rock and flow bedded pebbly mudstone. This sequence marks the transition zone between the New Bay Formation and the Dunnage Mélange. Thus, these fossils are the first to be associated with the New Bay Formation and represent the third fossil find in the Dunnage Mélange.

The conodonts are black, probably due to thermal metamorphism related to either nearby Ordovician gabbro or more distant Devonian granodiorite. Protopanderodus variocostatus has an upper range limit of lower Caradocian (Nemagraptus gracilis zone); the lower range limit is uncertain, though it has been reported as low as the Llanvirnian. This is a common species in this time range.[1] Thus, the age of the limestone block is probably lower Middle Ordovician. The age of the limestone is significant in that:

(1) it is the youngest fossil recovered from the mélange and its age is in full accordance with the suggested age of the melange (see chap. 2)

---

[1]Bergström, S.M., 1971. Conodont Biostratigraphy of the Middle and Upper Ordovician of Europe and Eastern North America, GSA Memoir 127, p. 83-162.

(2) it supports the idea of lateral interdigitation of the Dunnage with part of the Exploits group, as discussed in 3-3.

(3) it is the first paleontological age determination for the New Bay Formation, and indicates that deposition of part of the New Bay Formation, all of the Lawrence Head Volcanics, and the Lawrence Harbour Shale were deposited over a relatively short span of time, as the Lawrence Harbour Shale contains a typical *Nemagraptus gracilis* fauna.