THE NEW WORLD ISLAND COMPLEX AND ITS RELATIONSHIPS TO NEARBY FORMATIONS, NORTH-CENTRAL, NEWFOUNDLAND

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by

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FRONTISPIECE: View of Duck Island from Mussel Cove in the New World Island Complex, with Silurian shale in foreground. Milliners Arm Formation to right.

ABSTRACT

The New World Island Complex consists of chaotically mixed volcanic and sedimentary rocks in a 1 km wide belt that extends 30 km southwestward from Cobbs Arm, on eastern New World Island, centrally located in the Dunnage Zone of the Newfoundland Appalachians. The complex comprises four lithic units, locally preserved in partial stratigraphic sections:

Squid Cove Volcanics - basalts (non-orogenic tholeiites), autoclastic breccias, red shale, limestone, pyroclastic breccias and tuffs (Arenigian to Llandeilian);
Cobbs Arm Limestone (Llandeilian);
Rodgers Cove Shale - interbedded black shale and chert (Caradocian); and
Muddy Cove Clastics - quartzitic greywackes, shales, polymictic conglomerates, and shaly conglomeratic breccias (Ashgillian to Llandoverian).

Imbricated slices of competent volcanic rocks over 3 km long are separated by mylonitic and clastic shear zones. Intervening sedimentary slices contain boudinaged interbeds (1 cm to 100 m across) and tight fold hinges. These pass laterally into melange with discrete blocks of volcanic rocks, sandstones, and locally black shale in a sedimentary matrix. The blocks have sheared margins in places, and one large slab of Ordovician limestone is deeply penetrated by

Silurian shale. Angular fragments in shaly conglomeratic breccias include black shale and limestone derived from the local stratigraphic section in adjacent fault blocks; one limestone clast is inhomogeneously deformed.

The New World Island Complex is followed to the northwest by sandstones and conglomerates (Crow Head Formation) of Upper Ordovician to Silurian age. These are locally continuous with Caradocian black shale and older rocks in the complex. Farther northwest, pre-Caradocian volcanic rocks like those in the New World Island Complex (Clarkes Cove Volcanics) are unconformably overlain by coarse Silurian conglomerates (Indian Cove Formation) in another structural slice.

The New World Island Complex structurally overlies Silurian conglomerates (Milliners Arm Formation) to the southeast. Compared to sediments of the same age in the third slice to the northwest (Indian Cove Formation), these were deposited farthest from a source area that lay to the northwest.

Steeply dipping faults in the New World Island Complex are locally folded by folds related to cleavage, and elsewhere truncate folds of the same generation.

The New World Island Complex is viewed as having formed by syn-sedimentary thrusting which juxtaposed Ordovician rocks with unlithified Silurian sediments, incorporated them as blocks within sedimentary matrix, and telescoped a southeast-facing basin.

TABLE OF CONTENTS

LIST OF MAPS

LIST OF FIGURES

LIST OF TABLES

LIST OF PLATES

CHAPTER I

INTRODUCTION

1.1 Regional setting and location of the New World Island Complex

New World Island is centrally located in the Dunnage Zone (Williams 1979) of the Newfoundland Appalachians (Fig. 1). To the northwest are island arc volcanic sequences of Lower to Middle Ordovician age (e.g., Kean and Strong 1975). New World Island consists mainly of marine clastic sequences of Upper Ordovician to Lower Silurian age (Fig. 2) separated by narrow chaotic zones of melange. The Dunnage Melange (Kay and Eldredge 1968), namesake of the Dunnage Zone, crops out along the southern shore of New World Island and on islands in Dildo Run to the southeast.

Volcanic rocks to the northwest of the New World Island Complex are unconformably overlain by Silurian redbeds, indicating they were involved in the Middle Ordovician Taconic Orogeny, an arc-continent collision (e.g., Williams 1975). On New World Island, Silurian marine clastic rocks overlie Ordovician pelagic deposits conformably and represent a clastic margin southeast of the collision zone.

The New World Island Complex is a 1 km wide melange

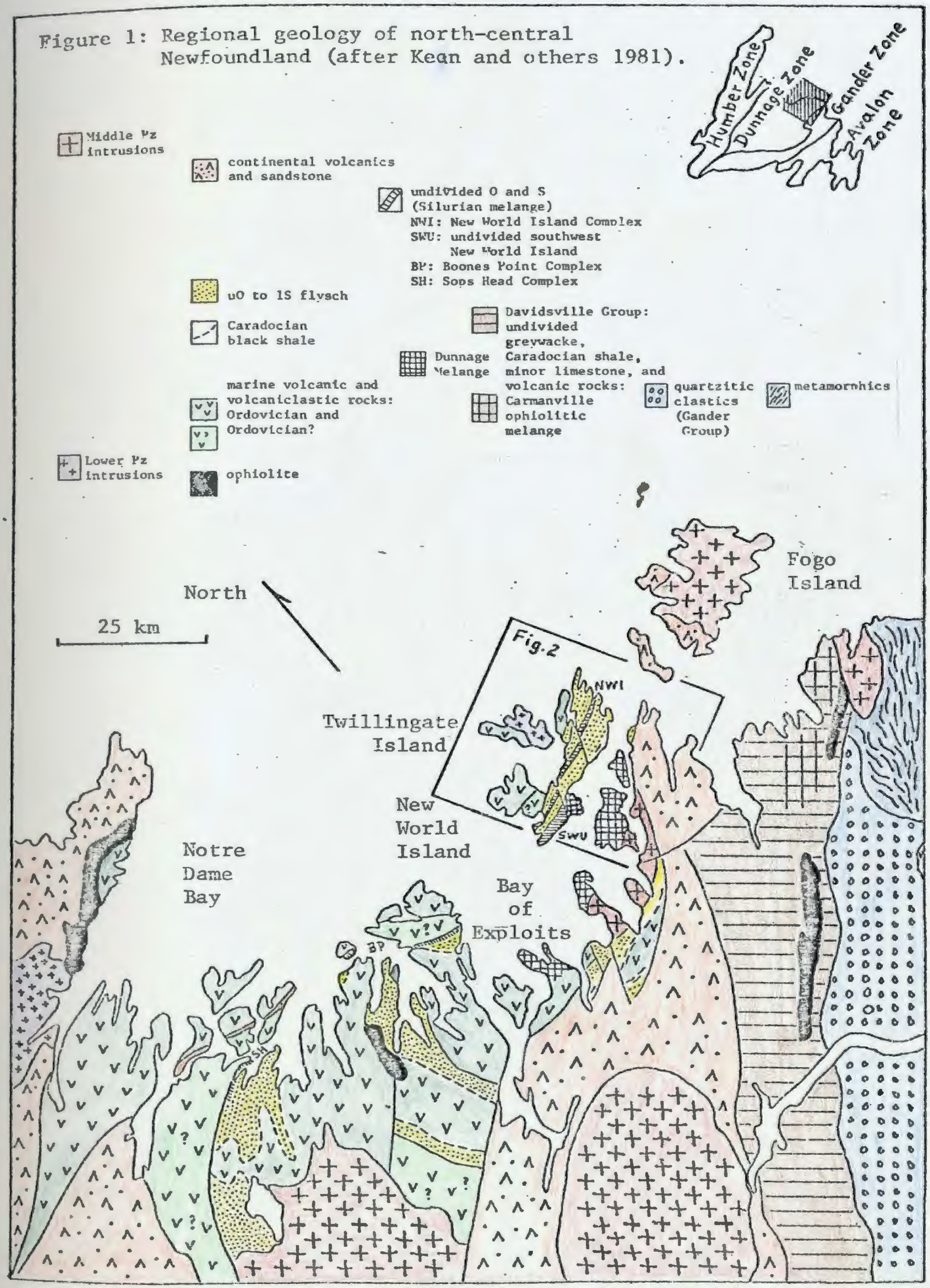

Figure 1: Regional geology of north-central Newfoundland (after Kean and others 1981).

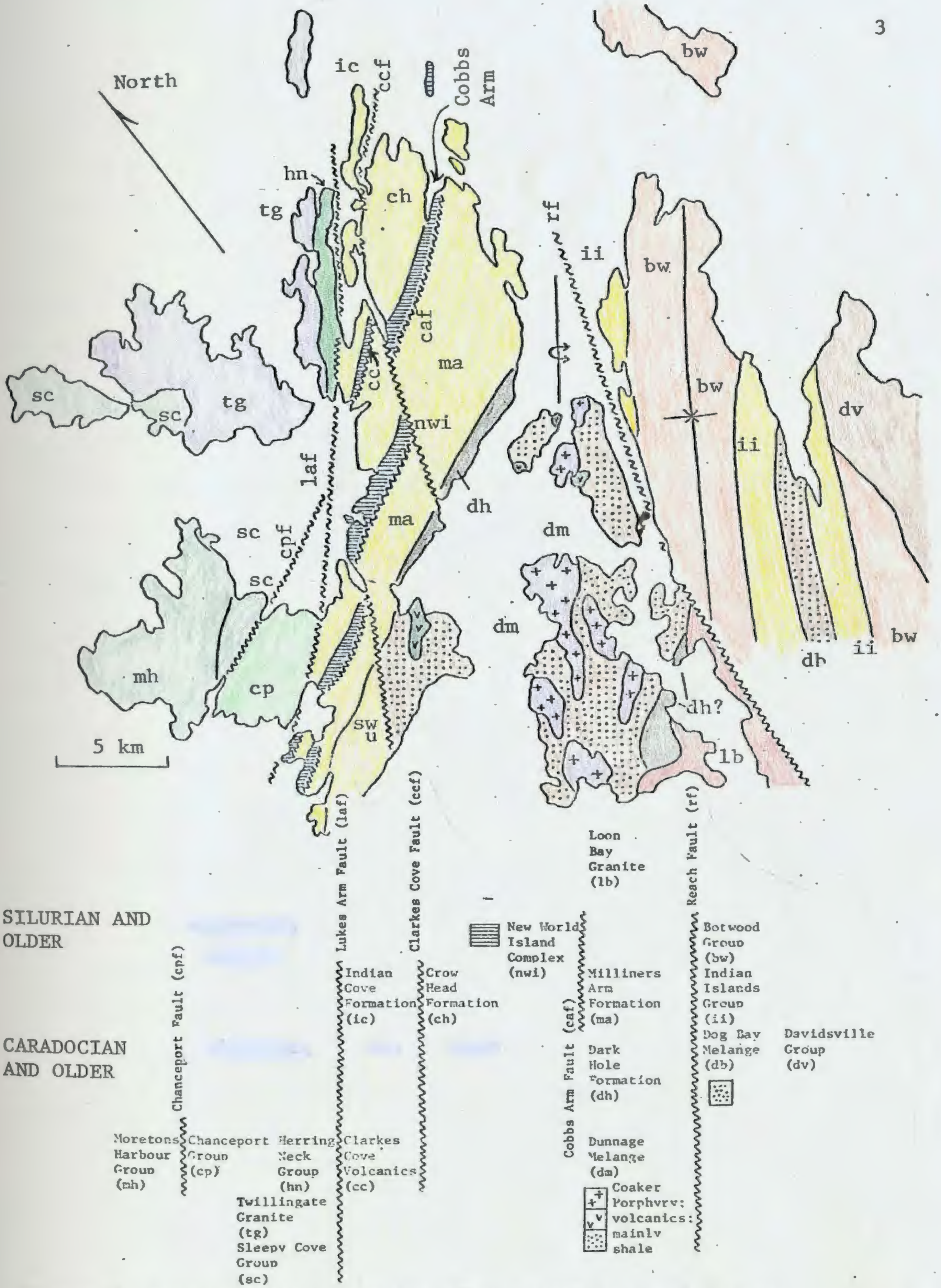

Figure 2: Local geologic setting of New World Island (after Williams and Payne 1975; Hibbard and Williams 1979; and Karlstrom 1982).

developed between marine clastic sections of Upper Ordovician to Lower Silurian age. The complex extends from Cobbs Arm on eastern New World Island 30 km to the southwest. Blocks in the melange include mainly volcanic rocks of Lower to Middle Ordovician age. These are set in a sedimentary matrix, locally Silurian shale.

Definition of melange

Melange, strictly a descriptive term with no genetic significance, means "a chaotic, heterogeneous assemblage of unsorted blocks set in a fine-grained matrix, the larger blocks being of outcrop size" (Hibbard and Williams 1979).

1.2 Current interest in New World Island

Current interest in New World Island focuses on Silurian melange that is well-exposed along the shores of Cobbs Arm, specifically whether volcanic rocks within it occur as mountain-size olistoliths in a spectacular submarine landslide deposit (McKerrow and Cocks 1978) or belong to part of a thrust-imbricated section (Kay and Williams 1963; Dean and Strong 1977; Nelson 1981) or transcurrent fault zone (Kay 1967). The origin of the melange and its relationships with nearby formations bear crucially on paleogeography and structural history of the area.

Melanges of central Newfoundland, including the nearby Dunnage Melange, have in general been variously interpreted as tectonic in origin (Dewey 1969; McKerrow and Cocks 1978) or as olistostromes (Hibbard and Williams 1979; McKerrow and Cocks 1978). Compared to melanges of western Newfoundland, which occur between major thrust sheets, their tectonic settings are poorly known. The New World Island Complex provides one of the best opportunities in central Newfoundland to attack the problem of melange formation because 1) all its major components are paleontologically dated, 2) coastal exposures are excellent, and 3) it is relatively limited in extent and localized along lithologic belts of unusual lateral persistence.

With regard to accretionary history of the Appalachian Orogen, the position and age of the Silurian New World Island Complex immediately to the east of the Taconic arc-continent collision zone make it of more than local interest, since accretionary events following the Middle Ordovician Taconic Orogeny are completely open to debate.

1.3 The present study: objectives and methods

The main intent of this study is to establish the origin and mechanism of formation of the chaotic New World Island Complex, its relationships with nearby groups, and its overall significance in the geology of northeastern Newfoundland.

Specific objectives were to:

1) map the complex, distinguishing blocks and matrix, to establish stratigraphic and structural relationships among its components and with nearby groups; and

2) describe volcanic rocks and determine their chemical affinity with the intent of establishing their tectonic setting.

Geologic mapping and field study of eastern New World Island were conducted from May to September 1981. The main area of study extends 20 km along the New World Island Complex from Virgin Arm to Duck Island and is generally 1 km in width. Critical areas nearby were also examined. Black and white airphotos (1:30,000), colour airphotos (1:12,500), and orthophotos (1:12,500) were available for location purposes in the field.

Thin sections of representative rocks from the New World Island Complex were examined to determine their make-up and significance. Eighteen basalts were analyzed by X-ray fluorescence (for trace elements) and by atomic absorption spectrophotometry (for major element oxides). Twenty-eight pyroxenes from 5 basalts were analyzed using the electron microprobe.

1.4 General geologic framework of eastern New World Island

The sequence across eastern New World Island from Dildo Run in the southeast to the Lukes Arm Fault in the northwest (Fig. 3) includes:

	(northwest)
Indian Cove Formation (Llandoverian) Clarkes Cove Volcanics (pre-Caradocian)	INDIAN COVE SLICE
BYRNE COVE MELANGE	
Crow Head Formation (Caradocian? to Llandoverian) NEW WORLD ISLAND COMPLEX	CROW HEAD SLICE
Milliners Arm Formation (Caradocian to Llandoverian) Dark Hole Formation (Caradocian) DUNNAGE MELANGE	MILLINERS ARM SLICE
	(southeast)

The large Milliners Arm, Crow Head, and Indian Cove slices are separated by chaotic zones, the New World Island Complex and Byrne Cove Melange, comprising many smaller blocks. The Crow Head slice may locally include rocks within the New World Island Complex at its base where the two appear to be in stratigraphic continuity. The Byrne Cove Melange is distributed at the base of the Indian Cove slice along the Clarkes Cove Fault, which truncates the entire Crow Head Formation.

Stratigraphic units within the Milliners Arm, Crow

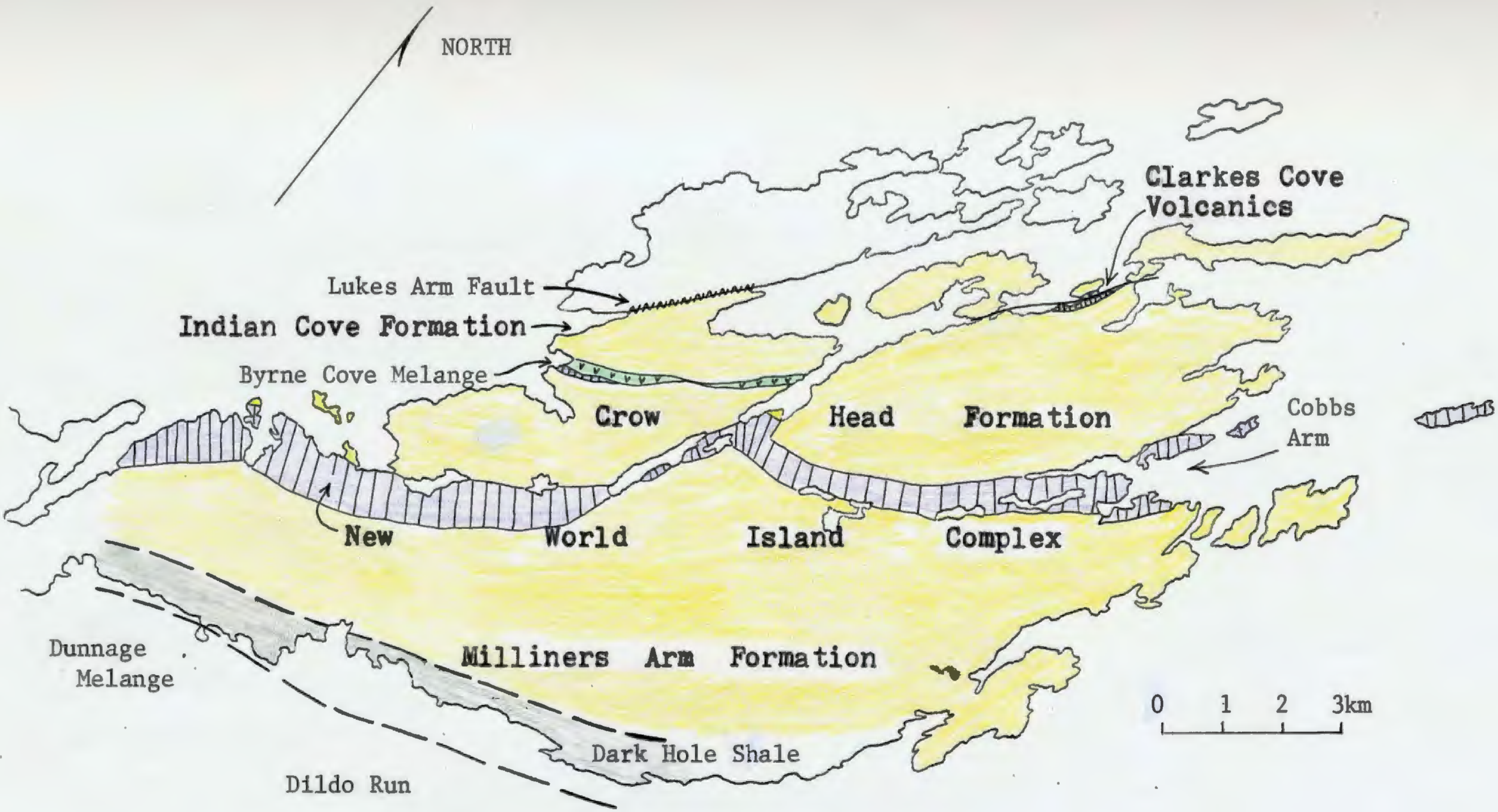

Figure 3: Main units of concern on eastern New World Island.

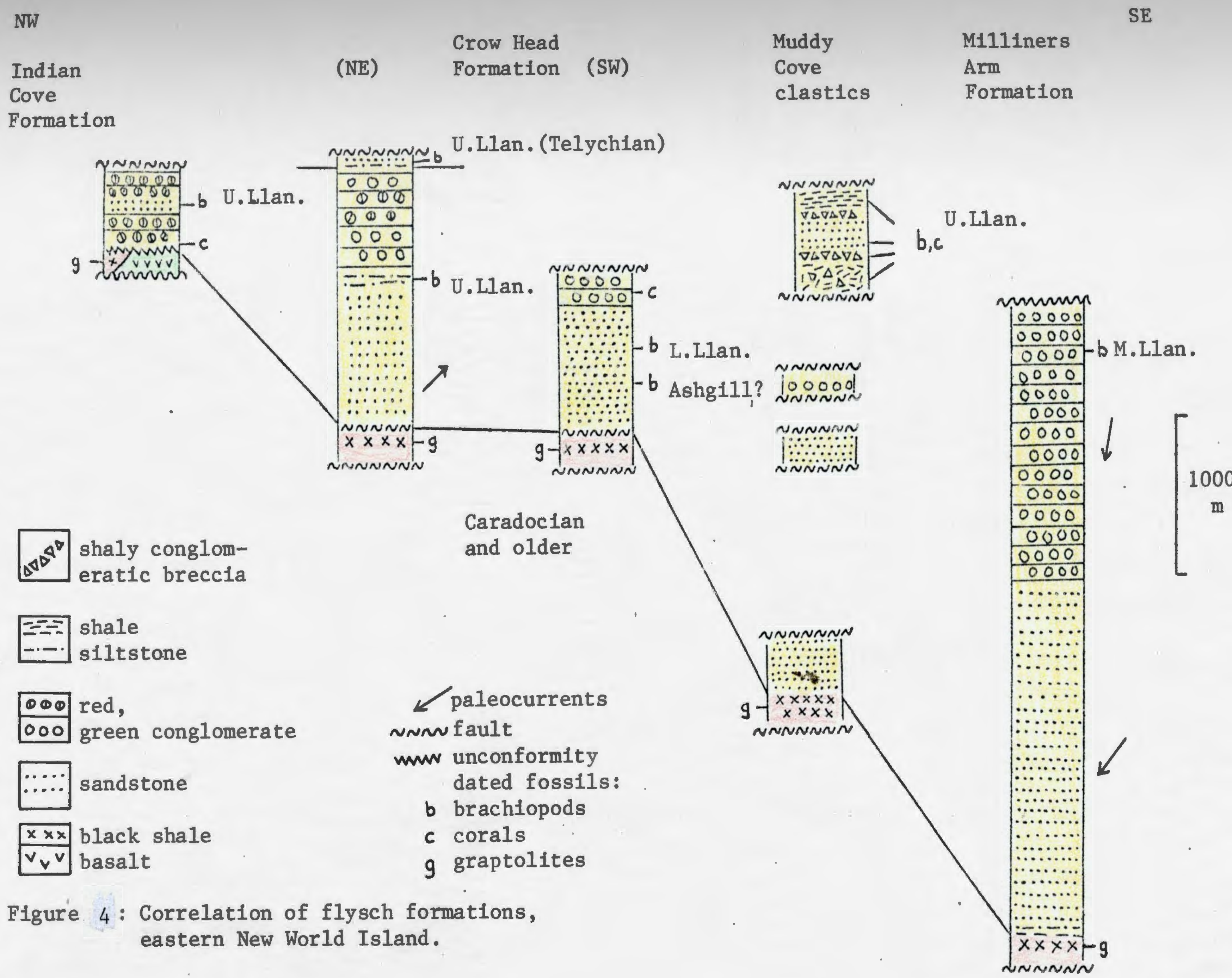

Figure 4: Correlation of flysch formations, eastern New World Island.

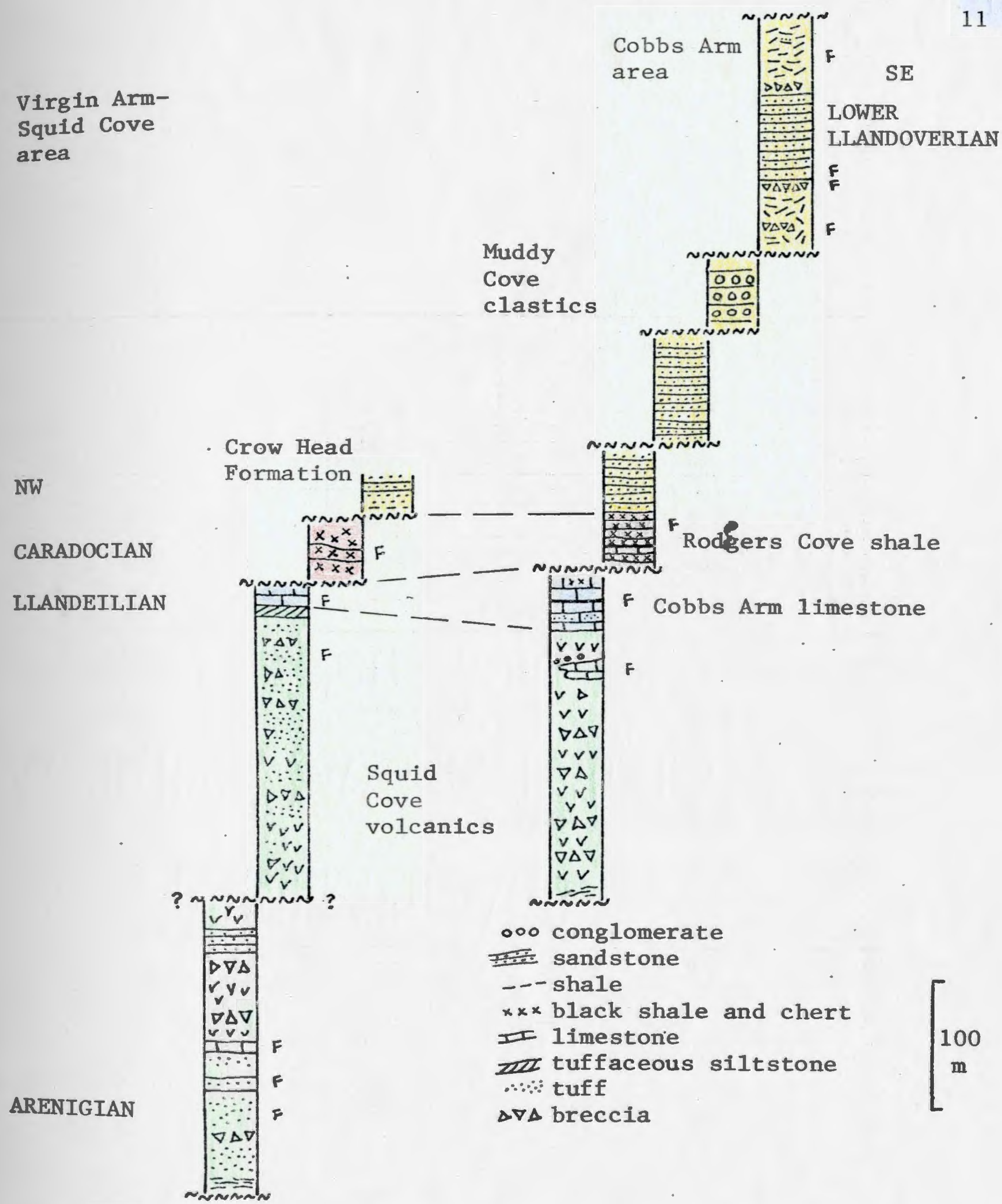

Figure 5: Partial stratigraphic sections from the New World Island Complex.

Head, and Indian Cove slices are correlative (Figs. 4 and 5). For example, each slice contains pre-Caradocian volcanic rocks, Caradocian shale, and post-Caradocian clastic rocks.

Incompetent rocks are affected by a steeply dipping cleavage, which is axial planar to climactic (F2) folds (Fig. 6). Pre-cleavage (F1) folds are overprinted by cleavage.

The Cobbs Arm Fault, which juxtaposes the New World Island Complex with the Milliners Arm Formation, related faults within the complex, and the Clarkes Cove Fault are all inclined at a small angle to stratigraphic units. Movement along these faults occurred prior to the end of deposition, i.e. they are syn-sedimentary, and continued past climactic (F2) folding.

The Burnt Arm Fault and related late cross faults truncate stratigraphic units and climactic (F2) folds but are not affected by any later folding.

A minor group of cross faults, restricted to the New World Island Complex and probably to volcanic rocks within it, may be pre-Caradocian structures.

Minor quartz-phyric felsic dikes intrude the youngest

POST ACADIAN		minor late folds (F3)	late faults
ACADIAN	cleavage	climactic folds (F2)	
			main faults
(EARLY SILURIAN)		pre-cleavage folds (F1)	

Figure 6 : Correlation of structures.

formations of eastern New World Island. Several types of intermediate dikes may be related to pre-Caradocian volcanic rocks within the New World Island Complex.

1.5 Definition of the New World Island Complex

The name New World Island Complex is proposed for the heterogeneous belt of chaotically mixed volcanic and sedimentary rocks approximately 1 km in width that extends 30 km across New World Island from Duck Island southwestward through Cobbs Arm to Virgin Arm and beyond. The complex occurs between conglomerates of the Milliners Arm Formation to the southeast and sandstones of the Crow Head Formation to the northwest (Fig. 7). The section across Cobbs Arm from Mussel Cove to Reddicks Cove serves as a type locality for the New World Island Complex. The term "complex", according to the North American Commission on Stratigraphic Nomenclature (1981), is lithodemic and equivalent in rank to group.

The New World Island Complex comprises several lithic units in approximately the following proportions:

Squid Cove Volcanics	65%
Cobbs Arm Limestone	5%
Rodgers Cove Shale	5%
Muddy Cove Clastics	
Muddy Cove sandstone	10%
Muddy Cove conglomerate	4%
Muddy Cove shale	10%
Muddy Cove breccia	1%

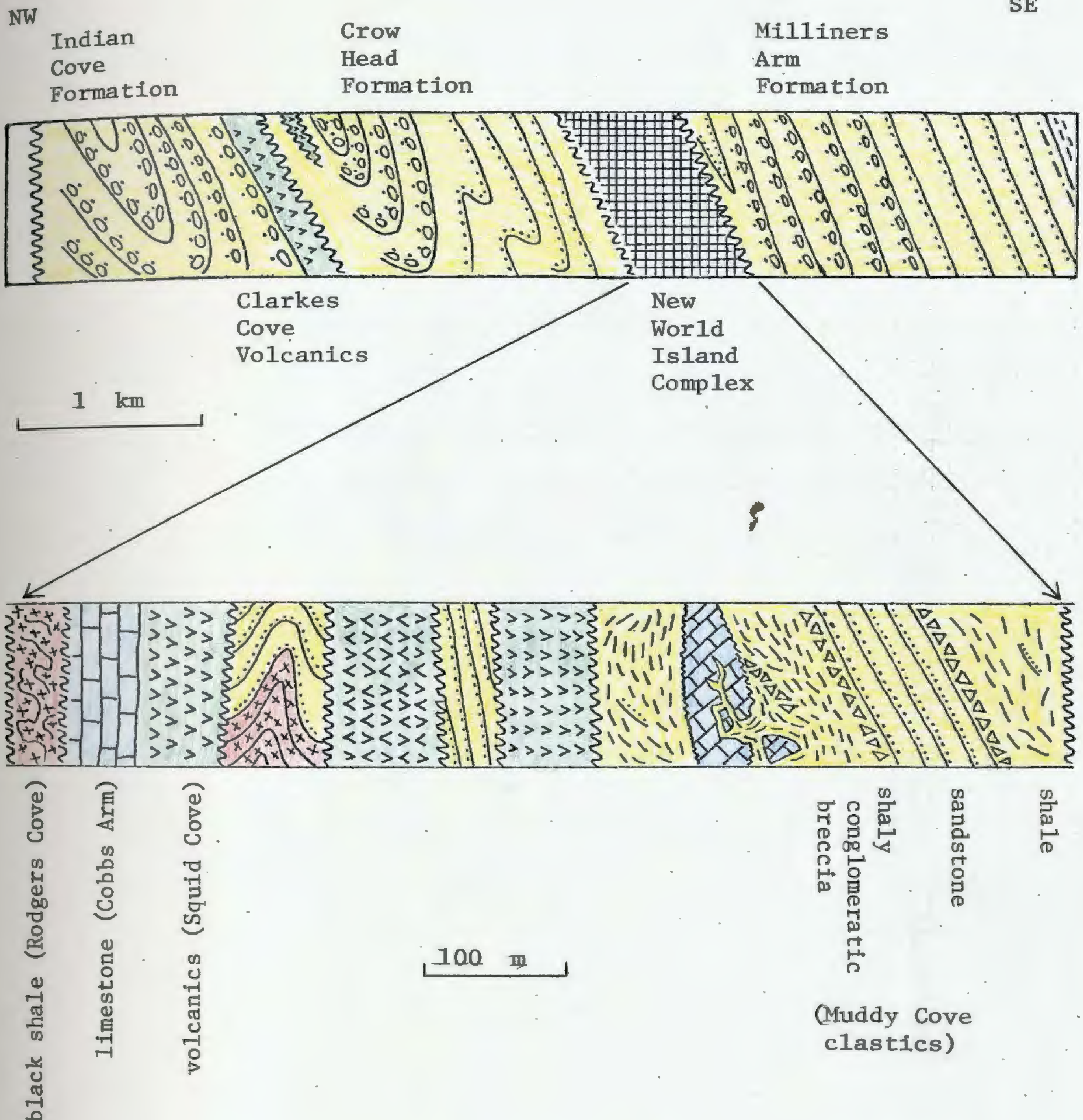

Figure 7 : Rock units of eastern New World Island.

Numerous partial stratigraphic sections occur in different blocks within the complex. The Squid Cove Volcanics of Lower to Middle Ordovician (Arenigian to Llandeilian) age are conformably overlain by the Cobbs Arm Limestone of Middle Ordovician (Llandeilian) age. No stratigraphic contacts are preserved between the Cobbs Arm Limestone and the Rodgers Cove Shale of Middle Ordovician (Caradocian) age, but an initially conformable contact between the two units is inferred. The Muddy Cove Clastics of Upper Ordovician to Lower Silurian (Caradocian to LLandoverian) age conformably overlie the Rodgers Cove Shale.

The New World Island Complex refers to essentially the same body of rocks as the Cobbs Arm Fault Zone of Kay (1976).

1.6 Previous work

Early work in the New World Island area by Jukes (1842), Murray and Howley (1881), Princeton University expeditions during 1916 to 1918, Heyl (1936), Twenhofel and Schrock (1937), and Baird (1953) consisted mainly of reconnaissance investigations and some fossil collecting. Williams (1957) made an outcrop map showing the distribution of lithologies between Cobbs Arm and Burnt Arm and later (1963) produced an inch = one mile map of Twillingate and New World Islands. Harris (1966) made a detailed map of the area immediately around Cobbs Arm as part of an M.Sc. project. Marshall Kay mapped and studied the New World Island area for over a decade (Kay and Williams 1963; Kay 1967; Kay 1976); several of his students, Horne (1968), Helwig (1967), Eastler (1969), and Jacobi (1979), conducted general studies nearby for Ph.D. theses. Paleontological studies by Dean (1971; 1974), Bergstrom, Riva, and Kay (1974), Neuman (1976), McKerrow and Cocks (1978; 1981), and Hunter (1978) have contributed considerably to the age control of various units in the Cobbs Arm area. Watson (1981) and Arnott (1982), students of McKerrow, have recently completed mainly sedimentological studies of the Upper Ordovician to Silurian clastic sections on eastern New World Island. A structural study of these same rocks by van der Pluijm is in progress.

1.7 Previous interpretations and contributions

Murray and Howley (1881) interpreted the Lukes Arm Fault as an unconformity separating the Ordovician volcanic rocks of Notre Dame Bay from Silurian rocks of eastern New World Island. Although Howley noted the resemblance of volcanic rocks in the New World Island Complex to those within the Ordovician basement, he viewed them as part of the Silurian cover; misidentified fossils were used erroneously to substantiate a Silurian age for the volcanic rocks.

Twenhofel and Schrock (1937) regarded the entire section southeast of the Lukes Arm Fault, from Dildo Run past Cobbs Arm to Pikes Arm, as a single northwest-facing conformable sequence. Conglomerates south of Cobbs Arm (upper Milliners Arm Formation) that resemble Silurian conglomerates at Pikes Arm (upper Crow Head Formation) were thought to be Ordovician based on their position to the south of the Ordovician volcanic rocks at Cobbs Arm.

Williams (1957) expanded on the interpretation by Twenhofel and Schrock (1937) (Fig. 8). Silurian strata occupy the cores of synclines on the Port Albert Peninsula to the south of Cobbs Arm (Patrick 1954) and at Pikes Arm to the north; an intervening anticline between the Port Albert Peninsula and New World Island had been suggested by

	Williams 1957	Williams 1963	Harris (1966)	Kay 1976	
SILURIAN AND OLDER	map unit 4 (northern belt) (sandstone and conglomerate)	Botwood Group (map units 9 and 10) map unit 10 (includes Pike Arm Formation) map unit 9 (Goldson Formation) map unit 8	map unit 6 (conglomerate) map unit 5 (sandstone) map unit 4 (shale)	TOOGOOD SEQUENCE (northwest) Goldson Group	COBBS ARM SEQUENCE Goldson Group Sansom Graywacke
MIDDLE ORDOVICIAN (CARADOCIAN)	map unit 3 (black and grey shale)	map unit 7	map unit 3 (black shale)		Hillgrade Group Rodgers Cove Shale
MIDDLE ORDOVICIAN AND OLDER	map unit 2 (limestone) map unit 1 (volcanics) map unit 4 (southern belt) (conglomerate and sandstone)	map unit 6 map units 4 and 5	map unit 2 (limestone) map unit 1 (volcanics)	Summerford Formation	Cobbs Arm Limestone Summerford Formation

Figure 6: Summa
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		McKerrow and Cocks 1978	Reusch 1983			
H SEQUENCE Group aywacke	DILDO SEQUENCE (southeast) Goldson Group Sansom Graywacke	Goldson Group Pike Arm Formation Herring Head Formation Burnt Island Formation (west) Green Cove Formation (east) Toogood Formation Big Muddy Cove Group Mills Argillite Indian Cove Formation olistostrome Mills Argillite and blocks of: Milliners Arm Formation (Ashgillian) Dark Hole Formation (Caradocian) Rodgers Cove Shale (Caradocian) Summerford Group Cobbs Arm Limestone (Llandeilian) Cobbs Arm Lavas (Llandeilian) Virgin Arm Tuffs (Arenigian) Sansom Group Milliners Arm Formation	(northwest) Indian Cove Formation	Crow Head Formation Pike Arm member upper conglomerate Green Cove shale lower sandstone	New World Island Complex Muddy Cove Clastics	(sou Mill Form
Group s Cove Shale	Dark Hole Shale	Dark Hole Formation	Rodgers Cove Shale		Rodgers Cove Shale	Dark Shal
Arm Limestone d Formation	Cheneyville Formation Dunnage Formation	Dunnage Formation (tectonic melange)	Clarkes Cove Volcanics		Cobbs Arm Limestone Squid Cove Volcanics	Dunn Mela

gure 6: Summary of stratigraphic interpretations on eastern New World Island.

...cks	Reusch 1983	Arnott 1983
...rmation ...d Formation ...d Green Cove ...west) Formation (east) ...mation ... Group ...ite ... Formation ... ...illite and blocks of: ... Arm Formation (Ashgillian) ... Formation (Caradocian) ...ove Shale (Caradocian) ...d Group ... Arm Limestone (Llandeilian) ... Arm Lavas (Llandeilian) ... Arm Tuffs (Arenigian) ... Formation	(northwest) New World Island Complex (southeast) Indian Cove Formation; Crow Head Formation: Pike Arm member, upper conglomerate, Green Cove shale, lower sandstone; Muddy Cove Clastics; Milliners Arm Formation	(northwest) (southeast) Goldson Formation; Byrne Cove Melange; Goldson Formation, Big Muddy Cove Formation; Joeys Cove Melange, Milliners Arm Formation
...rmation	Rodgers Cove Shale; Rodgers Cove Shale; Dark Hole Shale	Summerford Group; Summerford Group; Joe Whites Arm Shale
...on (tectonic melange)	Clarkes Cove Volcanics; Cobbs Arm Limestone, Squid Cove Volcanics; Dunnage Melange (?)	Dunnage Melange

...ions

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Baird (1946). Williams noted that, if the section from Dildo Run past Cobbs Arm to Pikes Arm is conformable, then it simply represents the northwest-facing limb between the Dildo Run anticline and the Pikes Arm syncline.

Conflicting with the interpretation by Twenhofel and Schrock (1937) of a single conformable sequence, Williams (1957) observed detritus in the conglomerates south of Cobbs Arm that resembles Ordovician lithologies found to the north. He reasoned that, if the conglomerates are younger than overlying Ordovician volcanic rocks, then the section from Dildo Run past Cobbs Arm to Pikes Arm can not be a single conformable one.

Kay and Williams (1963) found Silurian fossils in the conglomerates south of Cobbs Arm, thereby substantiating the hypothesis of Williams (1957). The Cobbs Arm fault was inferred to be a folded thrust fault separating the two belts of Ordovician and Silurian rocks. "The main belts seem to be separated by a high-angle fault, but the northerly belt may have been thrust northward over the southerly one, and the fault subsequently tilted northward; thus the rocks in the northerly belt may have been most southerly at deposition" (Kay and Williams 1963).

Kay admitted later (1967) that the logic for folded northwest-directed thrusts was faulty. His admission illustrates the difficulty of deciphering fault-fold relationships and determining their relative ages. "The evidence from northward-facing asymmetrical folds with south-dipping axial-plane cleavage suggests overthrust from the south. Yet such thrusts should have older rocks on the south side of the plane, whereas the faults bounding the parallel belts have younger, Silurian rocks south of the Ordovician rocks along the faults. Thus, the younger rocks would have to be thrust over the older." (Kay 1967, p.590). Also, "the thrust blocks, of the hypothesis would have had their original south-dipping axial-plane cleavage rotated to a northward dip, contrary to what is observed." (Kay 1967, p.591) Hence, "the writer believes that they are not thrust, but are transcurrent faults". (Kay 1967, p.590).

Kay and Williams (1963) reported an unconformity near Rogers Cove, where Silurian shale containing Ordovician detritus abuts Ordovician black shale and limestone. Williams (1963) also noted that Caradocian black shale along the northwestern margin of the New World Island Complex is interbedded with shale and sandstone of the turbidite section to the north. He was therefore forced to envision a Silurian paleogeography with local uplifted welts to explain conformity between the two systems in one place and disconformity in another.

Harris (1966) (Fig. 8) delineated three Silurian map-units consisting of mainly shale, mainly sandstone, and mainly conglomerate. The shale unit was considered oldest, based on the presumed unconformity at Rogers Cove, and the conglomerate unit youngest. A great recumbent fold system thrust towards the northwest accounted for the large scale repetition of the Ordovician and Silurian. Longitudinal faults that are abundant in the central belt through Cobbs Arm and that constitute Kay's (1967) transcurrent fault zone, were interpreted as normal faults. Oblique faults that cut across the main lithologic belts, were considered the youngest structures in the area.

Horne (1968) described several generations of structures, including slump folds, chaotic structure, primary and secondary folds of tectonic origin, and early, intermediate, and late faults. He noted that small scale folds northwest of the Cobbs Arm fault consistently indicate an anticline to the southeast.

Jacobi and Schweickert (1976), referring to the exposures at Rogers Cove, brought attention to melange comprised of isolated Ordovician volcanic and limestone blocks in a matrix of Silurian shale.

Dean and Strong (1977) pointed out that the Lobster Cove, Chanceport, Lukes Arm, Toogood (Clarkes Cove), and Cobbs Arm Faults occur at the stratigraphic tops of steeply dipping, north-facing sections. They thought that the faults were southeast-directed thrusts, later folded during the Acadian Orogeny. Their evidence for polarity included 1) small scale folds exposed at Fortune Harbour along the Chanceport Fault, 2) the affinity of the Moretons Harbour Group and Twillingate Granite with rocks in western Notre Dame Bay and on the Burlington Peninsula, and 3) the observed northwest dip of the Lobster Cove Fault at Springdale.

Silurian melanges west of New World Island, including the Sops Head and Boones Point Complexes, are overlain by volcanic rocks of the undated Roberts Arm and Cottrels Cove Groups, correlatives of the undated Chanceport and Ordovician Herring Neck Groups. They were interpreted by Dean (1978) as olistostromes initiated by the onset of Roberts Arm and Cottrels Cove volcanism' of presumed Silurian age. The presumed Silurian age of the volcanic rocks was conditioned by 1) their position north of Upper Ordovician to Silurian clastic rocks, even though the Lukes Arm Fault and its extensions intervene, and 2) their locally silicic character compared to dated Ordovician volcanic groups, even though such a facies difference might also be explained by distant transport along the faults.

McKerrow and Cocks (1978) dispensed with the unconformity of Kay and Williams (1963) and the model of fault-repeated sections. They postulated a huge olistostrome between the conglomerates south of Cobbs Arm and conglomerates near Indian Cove south of Lukes Arm Fault (Fig. 8). The olistostrome constituted the bulk of their Big Muddy Cove Group, and included the volcanic belt at Cobbs Arm (New World Island Complex), the clastic belt to the north (Crow Head Formation), and another volcanic belt at Little Byrne Cove (Clarkes Cove Volcanics and Rodgers Cove Shale). They envisaged olistoliths, no larger than several hundred metres across, of Ordovician volcanic rocks, limestone, black shale, and turbidites suspended in Silurian shale; hence the basement of Kay and Williams (1963) was interpreted merely as a large clast. They correlated turbidites and conglomerates in the clastic belt (Crow Head Formation) with the unslumped section south of Cobbs Arm (Milliners Arm Formation). Although they mentioned faulted or cleaved strata within blocks, and ductilely deformed matrix (p. 1125), they ignored the significance of extensive sheared rock localized within the volcanic belts. They were later (McKerrow and Cocks 1981) forced to postulate important syndepositional movement on the Virgin Arm and other cross faults to account for major differences in stratigraphy along strike.

Arnott (personal communication, 1981) showed that the clastic belt north of Cobbs Arm (Crow Head Formation), although intensely faulted, is a normally stratified section and not, as described by McKerrow and Cocks (1978), composed of olistoliths. He reduced the olistostromal horizon to include only the volcanic belt and associated rocks (New World Island Complex) that lie between the orderly sections north and south of Cobbs Arm. This model implies that the clastic section north of Cobbs Arm (Crow Head Formation) is younger than the supposed olistostrome (New World Island Complex) and conglomerates to the south (Milliners Arm Formation).

Arnott later acknowledged (1982) that the Crow Head Formation is not younger than, but correlates with the Milliners Arm Formation, its age being constrained by Caradocian graptolitic shale at its base within the northern margin of the New World Island Complex. He further reduced the extent of the olistostrome to an ill defined belt along the southeastern margin of the New World Island Complex (Fig. 8). Based on the differences in detail between the clastic sections north and south of Cobbs Arm (Crow Head and Milliners Arm Formations), he thought that each section was deposited in an independent basin, and the basins were separated by an active steeply dipping fault along which the intervening olistostrome was deposited.

Karlstrom and others (1982) differed with Dean and

Strong (1977), arguing that the rectilinear Chanceport and Lukes Arm Faults are steeply dipping faults, not thrusts, and post-date regional upright folds. Relative displacement on the Toogood (Clarkes Cove) and Cobbs Arm Faults again became a point of contention because the criteria of Dean and Strong (1977) were based on relationships to the north. Karlstrom and others (1982) attributed anomalous strain in a section near Fish Cove south of Cobbs Arm to preferential shearing in the southeast facing limb of a large, nearly upright fold. A similar model to explain ~~dis~~rupted strata in the Cobbs Arm belt is supported by remnants of southeast facing limbs along its southeastern margin. Karlstrom and others (1982) also suggested that melange in the New World Island Complex might be of Ordovician age and was infolded with Silurian strata, not realizing that the melange matrix is Silurian.

Nelson (1981) related chaotic horizons farther west in Notre Dame Bay to syn-sedimentary thrust faults and suggested this was also the case at Cobbs Arm. The horizons include subaqueous debris flow deposits, localized next to fault scarps, that were subsequently overridden and further disrupted by the southeast directed thrusts of Dean and Strong (1977). A local cleavage related to the thrusting was overprinted by a cleavage related to upright regional folding during the Acadian Orogeny. The model differs from that of Arnott (1982) in the dip of the syn-sedimentary fault. It implies that differences between the clastic sections north and south of Cobbs Arm are due to juxtaposition of far removed sections which were not necessarily deposited in separate basins.

ACKNOWLEDGEMENTS

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CHAPTER II

LITHIC COMPONENTS OF THE NEW WORLD ISLAND COMPLEX

The following chapter describes and interprets the four lithic units of the New World Island Complex.

2.1 Squid Cove Volcanics

Name, definition, distribution, and thickness

The name Squid Cove Volcanics is proposed for volcanic and related rocks within the New World Island Complex, which are of Lower to Middle Ordovician age. It is everywhere in contact with younger sediments, in many places along faults. Locally, it is depositionally overlain by the Cobbs Arm Limestone. Several hundred meters of section occur within the largest slices west of Burnt Arm.

The Squid Cove Volcanics was previously referred to the Summerford Group (Horne 1968; Dean 1978) or the Summerford Formation (Kay 1976). In the type area of the Summerford Group on southwest New World Island, Horne recognized six mappable units. Dean's revision of the Summerford Group, although he continued to refer to it as a group, included essentially one formation (volcanic Units Z, B, and D were found to be indistinguishable, Units C and

E were assigned to younger formations, and Unit A was found to be only a discontinuous member at the top of the single volcanic unit). No lithologic units could be separated within the Squid Cove Volcanics of the present study, although a wide age range of rocks suggests potential for biostratigraphic or chronostratigraphic subdivision.

Lithology

The Squid Cove Volcanics consists of a heterogeneous assemblage of mainly basaltic lavas and related volcaniclastic and sedimentary rocks (Plate 1). It includes several distinctive lithofacies, such as red shale, but, for the most part, rock types grade into one another. Volcaniclastic rocks, in particular, exhibit all degrees of gradation among lava, sandstone, and limestone end members.

Two common varieties of basalt include: red, amygdaloidal, plagioclase-phyric basalt and green aphyric basalt. A less common type of massive, gray, dense basalt occurs in several places along Virgin Arm intercalated with pyroclastic rocks. Amygdules, composed of calcite, locally exceed 1 cm in diameter. Large laths of plagioclase weather white and lend a distinctive porphyritic appearance to a section of red weathering basalt along the southeast shore of Duck Island. Dark green to black blebs of

Plate 1: Typical Squid Cove Volcanics, Duck Island: limestone interbedded in basalt breccia. Note stylolites in the fossiliferous limestone.

chlorite, from one to several mm across, are common. Calcite is common in thin veinlets to thicker masses, and some basalt has a bleached, drab green-brown appearance because of intensive alteration.

Many outcrops of basalt are massive, but pillow structure is locally evident (Plate 2). Flow folds occur in gray basalt at Fairbanks West.

Various types of autoclastic breccias are commonly associated with massive lava (Plate 3). Brecciated massive lava occurs along the west shore of Tilt Cove, the east shore of Tilt Cove Island, and Virgin Arm; it consists of angular, rhombohedral fragments ranging from 1 cm to 1 m that appear to have been shuffled somewhat with respect to one another (Plate 4). Pillows locally grade into broken pillow breccia with hyaloclastic to calcareous matrix (Plate 5). Flow breccias (LaJoie 1979) consist of lumpy to lensoid domains of basalt in a sheared foliated matrix (Plate 6). (Note: shearing that produced the fabrics of brecciated massive lavas and the flow breccias is thought to have been syn-extrusion, but this is not entirely certain; e.g., the fabric of the brecciated massive lava resembles that of intensely jointed peridotite from the base of a thrust sheet in western Newfoundland (Schillereff 1980).)

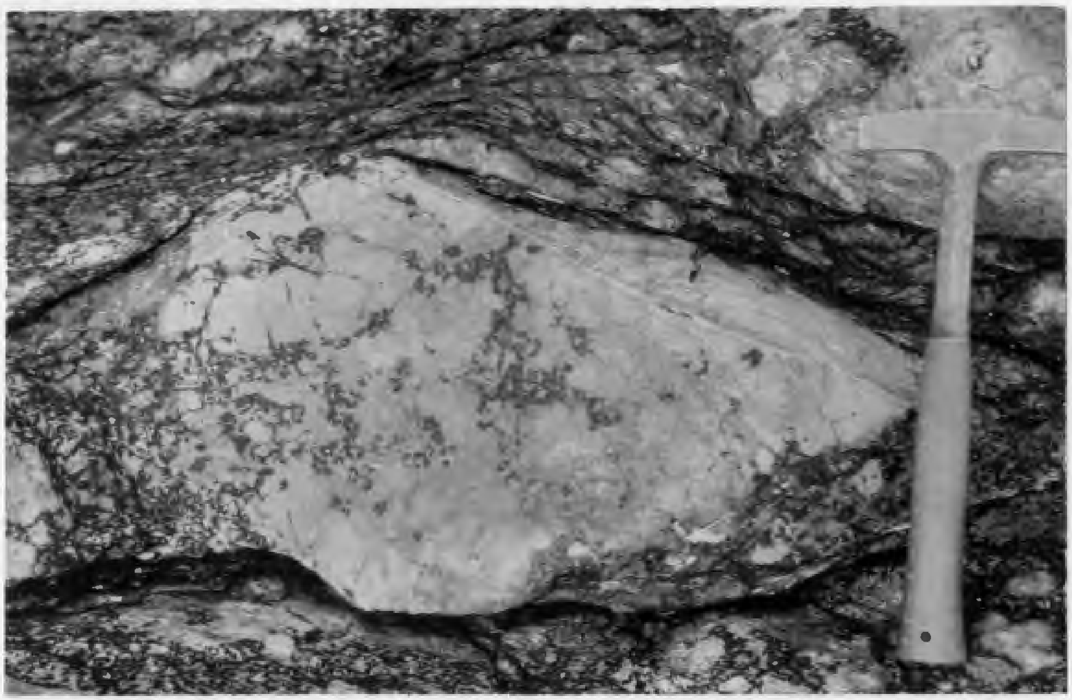

Plate 2: Sheared pillow of basalt, Squid Cove Volcanics, Virgin Arm. Chilled margin is locally preserved. Shearing produces chlorite schist.

Plate 3: Basalt flows and breccias, Squid Cove Volcanics, Boyds Island.

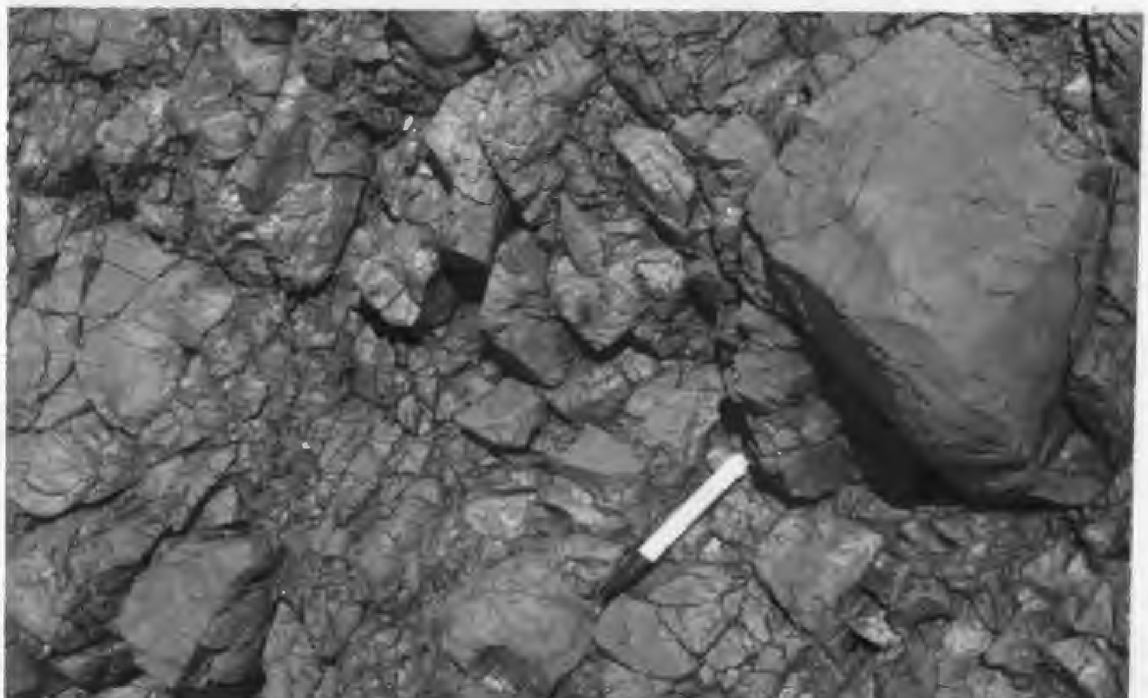

Plate 4: Brecciated massive basalt flow, Squid Cove Volcanics, Virgin Arm. Note intense rhombohedral jointing.

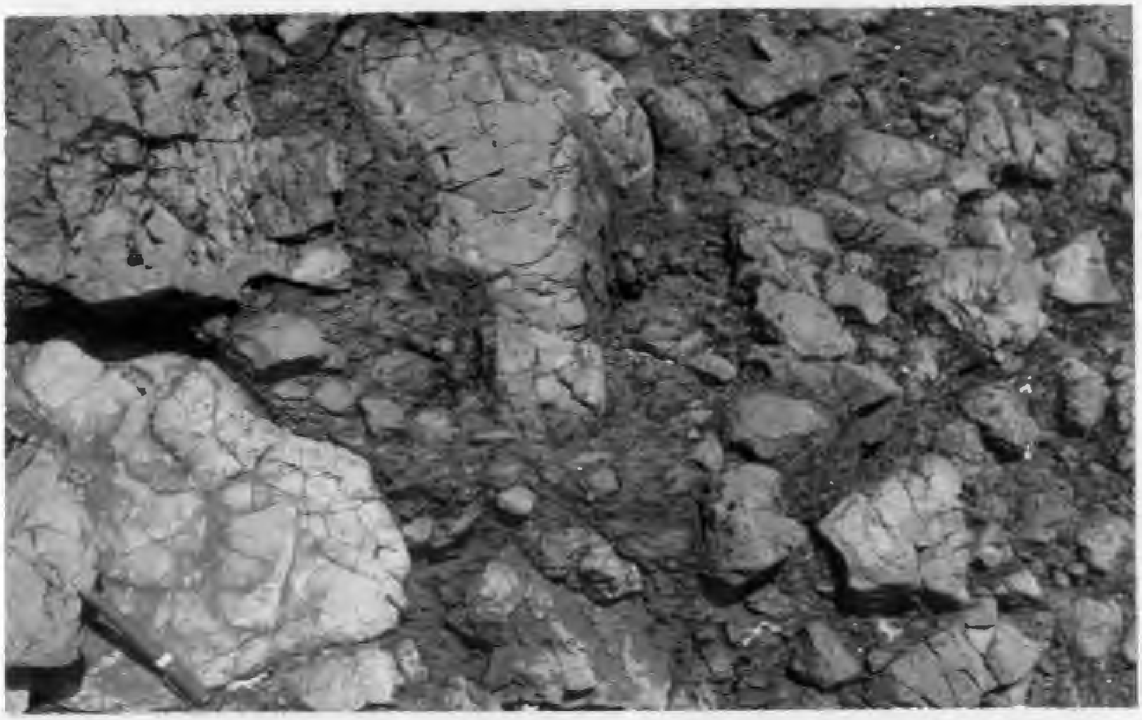

Plate 5: Broken pillow breccia: fragments of pillowed basalt in hyaloclastite matrix, Squid Cove Volcanics, Virgin Arm.

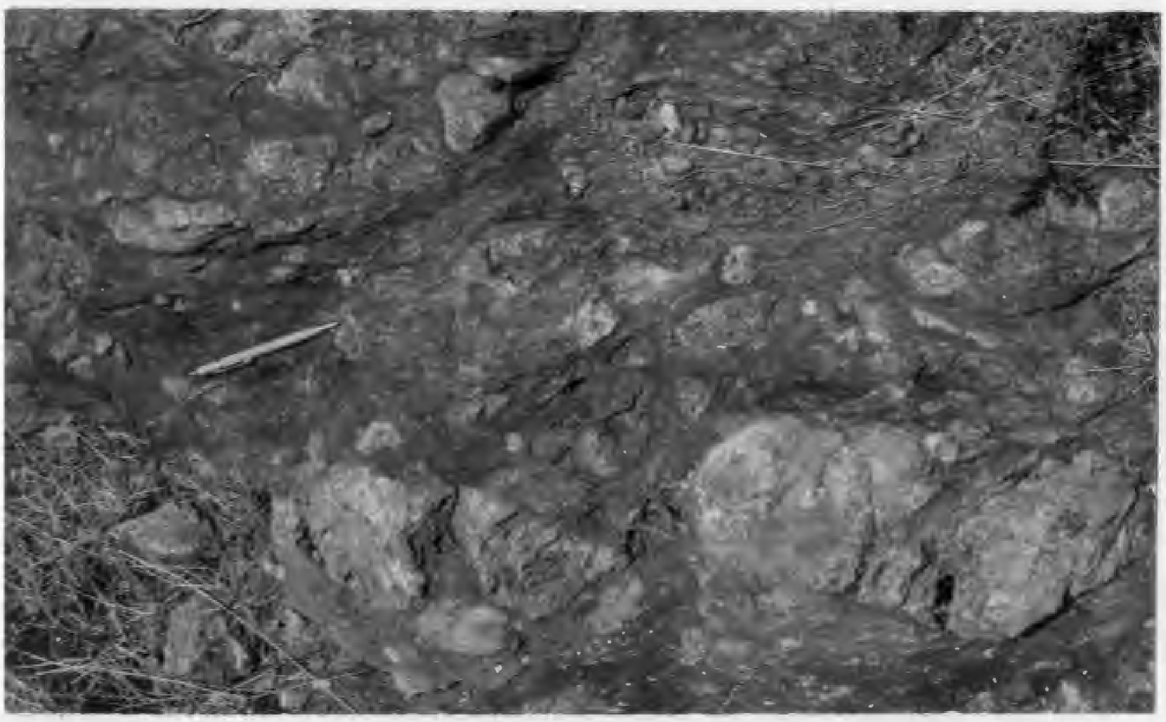

Plate 6: Basaltic flow breccia, Squid Cove Volcanics, near Cobbs Arm Fault east of Virgin Arm. Lumps of amygdaloidal lava are set in sheared matrix; shearing is thought to be syn-extrusion.

Flattened pillows of basalt along the shoreline north of Fairbanks West have been strongly sheared. Intensely sheared basalt consists of relict lenses of unstrained basalt enclosed by anastomosing chlorite.

Igneous rocks more felsic than basalt are rare. An outcrop near Fairbanks West consists of white, very amygdaloidal, perlitic rhyolite. Along the east shore of Tilt Cove, some quartz-phyric dacite occurs as either a flow, crystal tuff, or dike; it is conspicuously laminated in alternating gray, white, and orange bands and has a felsitic groundmass.

Abundant calcareous material in the Squid Cove Volcanics occurs with basalt in several diverse configurations. Interstices in volcanic rocks along Virgin Arm are concentrically lined with calcite (Plate 7) and also filled by graded beds of calcarenite that were deposited by currents flowing through the open spaces. Basalt fragments enclosed within calcareous matrix display a range of sizes and shapes. Small fragments of pillow rims, which appear to have been peeled off, occur within adjacent calcite (Plate 8). Large irregular fragments of basalt north of Fairbanks East appear to fit together and are not far travelled (Plate 9). Volcanic rafts to more equant fragments in limestone are generally fairly common (Plate 10). An unusual lapillistone bordering massive

Plate 7: Interstice in basalt lined by calcite, Squid Cove Volcanics, Virgin Arm. Note the concentric layers of calcite.

Plate 8: Fragments of chilled pillow margin in calcite, Squid Cove Volcanics, Virgin Arm. Note projection of pillow rim which was not completely torn off.

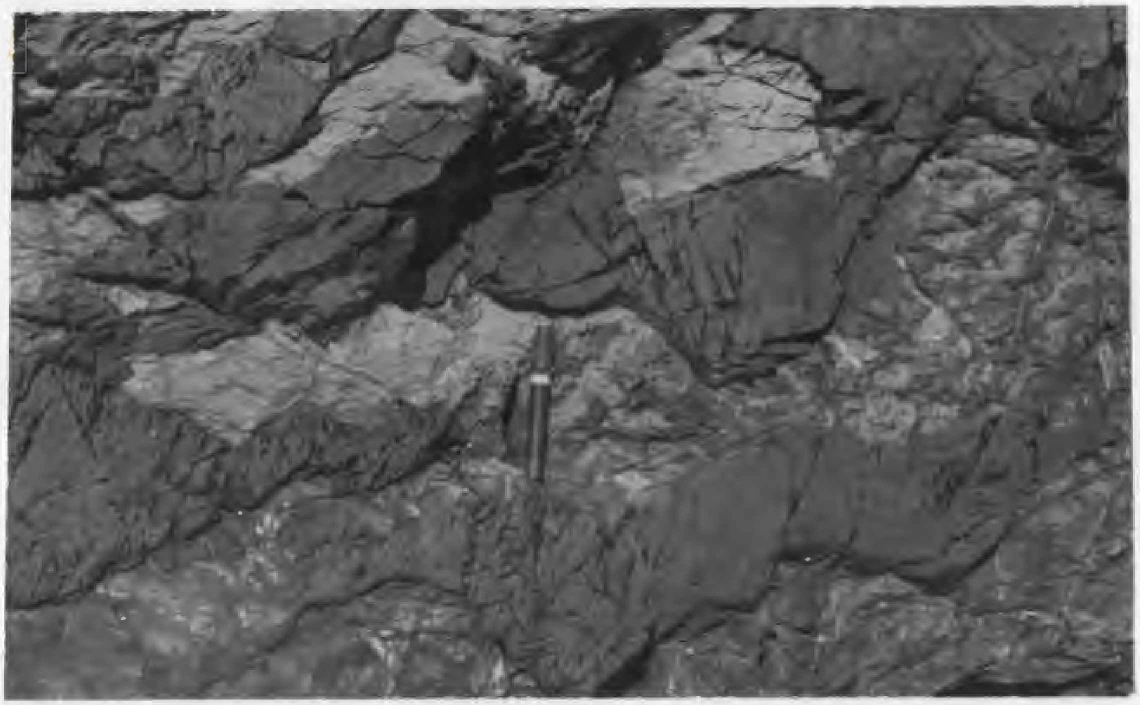

Plate 9: Irregular fragments of basalt in limestone, Squid Cove Volcanics, Fairbanks East. Fragments appear to fit together, indicating they are not far travelled.

Plate 10: Mixture of basalt and limestone, Squid Cove Volcanics, Boyds Island.

basalt consists of green basalt fragments suspended in calcareous material; the fragments become smaller and more loosely packed away from the massive basalt and achieve a perplexing configuration in which the fragments are not framework supported.

Calcite veins range from penetrative thin veinlets to large fissures. The larger fissures engulf thin slices to slabs of the volcanic wall rock, which break up into xenoliths in the essentially intrusive calcite. This secondary invasion of mobile calcite was probably related to tectonism.

Pyroclastic rocks are abundant in the western part of the Squid Cove Volcanics and comprise about half of the section. They are much less common in the east. They vary considerably in fragment size, stratification, amount of calcareous material, and fragment shape and composition. Genetic distinctions between fall and flow deposits or between tuff and epiclastic sandstone are generally difficult to make.

Pyroclastic breccias occur as thin horizons in tuffs to massive deposits. They consist of poorly sorted rubble to larger blocks of basalt and minor less mafic lava (Plate 11). The fragments are loosely packed with calcite filling the pore spaces. The angular fragments in some breccias

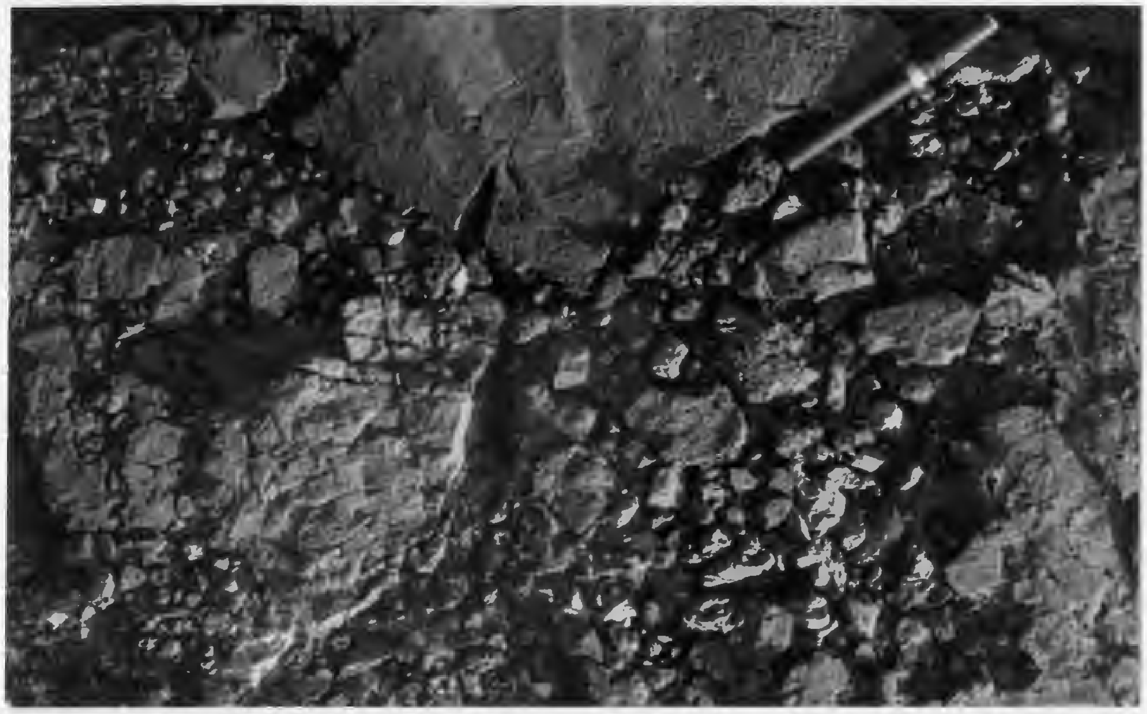

Plate 11: Pyroclastic breccia consisting of loosely packed basalt fragments and calcite cement, Squid Cove Volcanics, Virgin Arm.

Plate 12: Pyroclastic breccia, Squid Cove Volcanics, Virgin Arm. Note white rims around fragments.

have distinctive white, silicified rims (Plate 12).

Tuffs vary most conspicuously in the development of their stratification. In a distinctive section traceable across Squid Cove, bedding is well defined by alternating horizons of tuff and breccia every 2 to 20 cm. Faint to well developed laminations are commonly parallel (Plate 13). Calcite-rich lenses, aligned with the laminations, weather recessively (Plate 14). Cross laminated tuff occurs in 10 cm sets at Fairbanks West and in 1 m sets along the west shore of Tilt Cove Island. Massive green tuff occurs in the bottom of Squid Cove. A variety of massive tuff, which is commonly fossiliferous (e.g. at Fairbanks West and Fairbanks East), has irregular weathered surfaces due to an interweaving network of calcite-rich seams.

A peculiar volcaniclastic rock composed of a poorly sorted assemblage of volcanic clasts, which are matrix supported, occurs along Virgin Arm in the southeasternmost Squid Cove Volcanics.

Several varieties of sandstones occur in the Squid Cove Volcanics. Red and green massive sandstones contain rounded volcanilithic grains and fossil particles. Distinctive sandstone and conglomerate consisting of rounded volcanic grains and pebbles cemented by pure

Plate 13: Parallel laminated basaltic tuff, Squid Cove Volcanics, Virgin Arm.

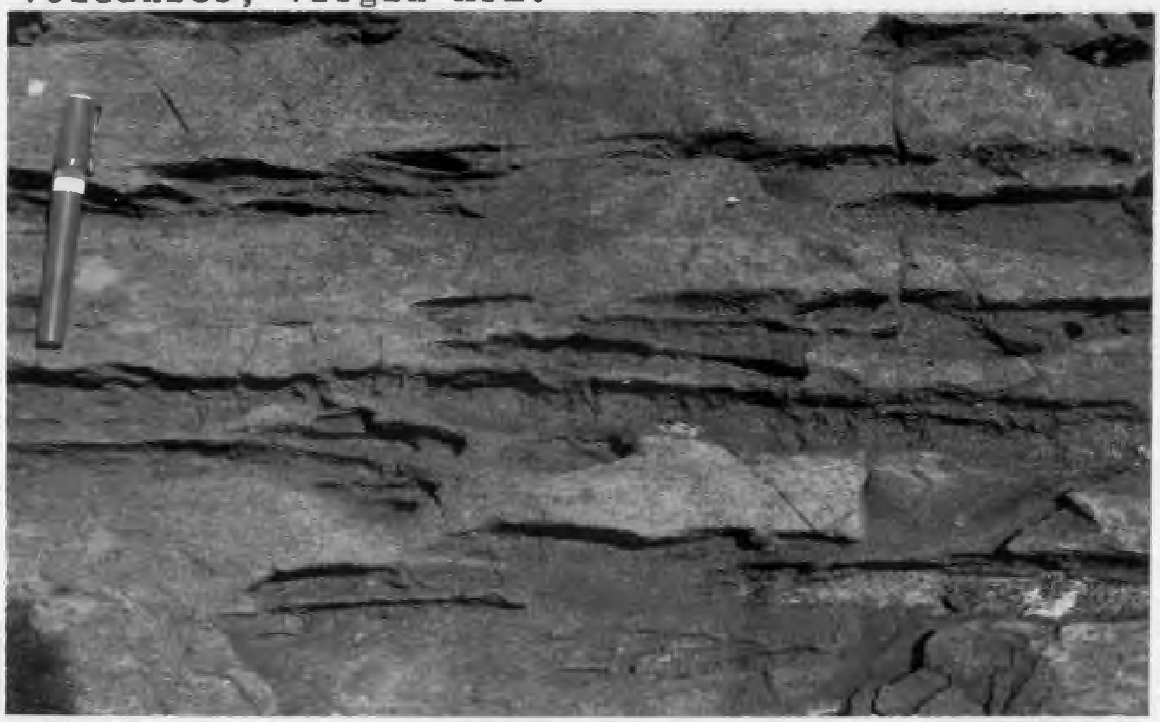

Plate 14: Tuff, faint parallel laminations, Squid Cove Volcanics, Virgin Arm. Recessive weathering lenses are calcite rich.

calcite occurs on Boyds Island and in Quarry Cove; the pebbles were probably rounded in a high-energy beach environment. A sandstone interbedded with limestone from the south shore of Duck Island resembles sandstone of the Muddy Cove Formation, but consists of mainly volcanilithic and plagioclase grains. Similarly, some medium bedded sandstones that are interbedded with volcanics at Fairbanks West and along Virgin Arm resemble turbidites of the Muddy Cove Clastics, but do not have well developed Bouma sequences.

Red shale occurs at several places within the Squid Cove Volcanics: viz. along the fault to the north of a turbidite section on the east side of Tilt Cove; near the entrance to the quarry along the paved highway to Twillingate; between the paved highway and Wallet Pond; in Quarry Cove; near the tip of Reddicks Cove Peninsula; and in many horizons in the basalt section of Duck Island. The shale is very fissile. Red shale occurs in an unusually thick lens at the tip of Reddicks Cove Peninsula, and, in every case, the shale is coincident with a zone of shearing. Inclusions of basalt, which vary from sand size particles to lozenges many cm long, are internally sheared along chlorite seams and appear to have been tectonically admixed.

A distinctive lithofacies, which occurs at Squid Cove and along Burnt Arm near the top of the Squid Cove Volcanics, consists of light green shale and dark green tuffaceous siltstone that are thinly interbedded in a very even, parallel manner.

Limestones in the Squid Cove Volcanics and the Cobbs Arm Limestone can only be distinguished by stratigraphic position or fossil content. Their lithologies are discussed under the next section on the Cobbs Arm Limestone.

Petrography of basalts from the Squid Cove Volcanics

Basalts from the Squid Cove Volcanics vary from aphyric to plagioclase-phyric and have ophitic through intergranular to intersertal textures. In addition, some lavas have a trachytic texture due to alignment of plagioclase crystals.

Green aphyric lavas generally have ophitic textures and contain plagioclase (labradorite), augite, chlorite-hematite replacements of olivine, chlorite, sphene (leucoxene), and an opaque mineral (probably a mixture of titaniferous magnetite and ulvospinel); prehnite occurs locally. They are commonly coarse and some green basalt may occur as dikes.

Red oxidized basalts, commonly plagioclase-phyric to micro plagioclase-phyric, have an opaque matrix, which is presumably hematite-rich. Amygdules consist of calcite and mixtures of chlorite and a distinctive green, potassium-rich mineral (celadonite?).

The most felsic gray basalts are plagioclase-phyric and have a dense, murky groundmass. Trachytic alignment of plagioclase is common. Mafic minerals are absent except for chlorite and minor opaques.

Geochemistry of basalts from the Squid Cove Volcanics

Squid Cove basalts are locally altered, for example veinlets of calcite are abundant in some rocks. Plagioclase is sporadically albitized. However, augites are fresh. Whole rock samples were trimmed to remove weathered and visibly altered parts. Only trace elements with a high ionic potential, believed to be immobile during alteration, are used in the following discussion.

Augites, generally considered to reliably reflect magma composition (e.g. Coombs 1963), have relatively high SiO_2, low Al_2O_3, low CaO, and intermediate TiO_2 values. They plot mainly in the subalkaline field on SiO_2-Al_2O_3

(Fig. 9) and Ti-Ca+Na (Fig. 10) diagrams with the exception of sample 50, which is transitional to alkaline. On the pyroxene quadrilateral (Fig. 11), they cluster around the trend for the tholeiitic Skaergaard intrusion and plot below values typical of alkali basalts. In support of a subalkaline affinity are 1) low Nb values (Table 1) and 2) clear augites rather than lavender high-titanium augites characteristic of alkaline basalts.

Squid Cove augites plot in the field of non-orogenic basalts on the Ti+Cr-Ca diagram (Fig. 12).

Whole rock analyses have intermediate Ti, Zr, Y, and Zr/Y values. These values, along with those for Nb and P2O5, are similar to or slightly greater than those for MORB (mid-ocean ridge basalt) (Fig. 13). They are much greater than values typical of volcanic arc basalts, which are depleted (relative to MORB) in these trace elements of high ionic potential. Squid Cove basalts plot within the MORB and ocean island fields on Ti-Zr (Fig. 14) and Cr-Y (Fig. 15) diagrams. On the Zr/Y-Zr diagram (Fig. 16), intended to discriminate between MORB and within-plate basalts according to Zr/Y, the Squid Cove basalts plot mainly in the MORB field.

In summary, the geochemistry of Squid Cove basalts suggests they are mainly tholeiites (including some olivine

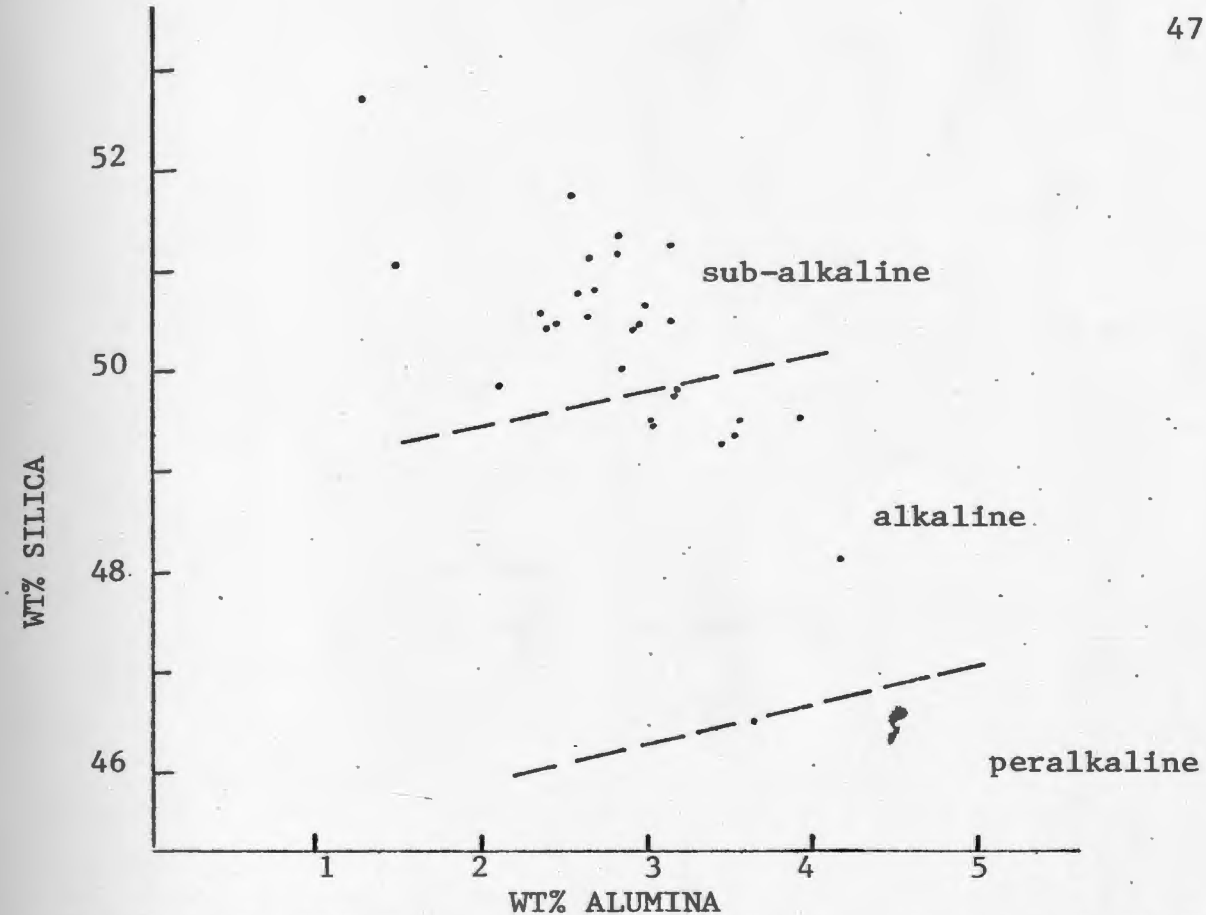

Figure 9: Plot of silica versus alumina for pyroxenes from Squid Cove lavas. The pyroxene analyses are from five different hand specimens. Boundaries of fields for pyroxenes from different rock types are after LeBas (1962).

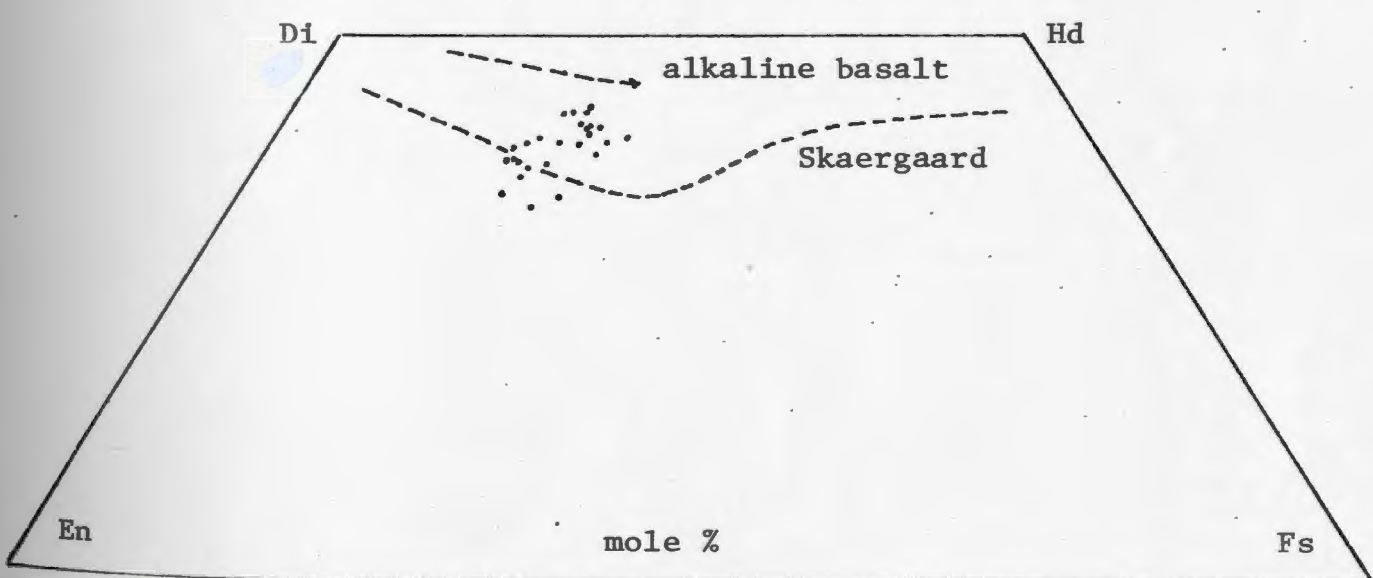

Figure 11: Plot of compositions of pyroxenes from Squid Cove lavas. Dashed lines are trends of pyroxene compositions in alkaline basalts and the Skaergaard intrusion, after Brown (1967).

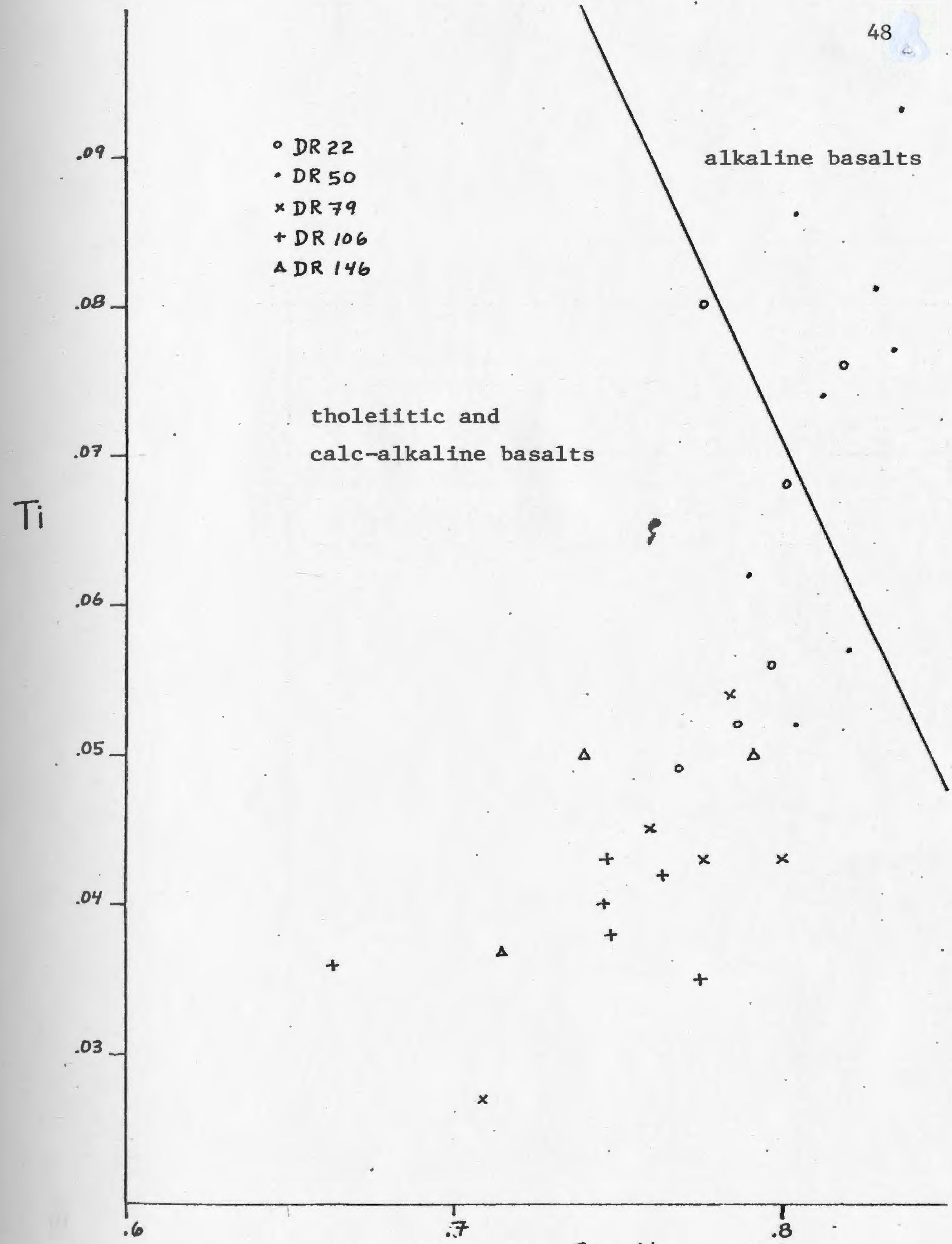

Figure10: Plot of Ti versus Ca + Na for pyroxenes from five basalts of the Squid Cove Volcanics, after Leterrier and others (1982).

TABLE I : MAJOR AND TRACE ELEMENT ANALYSES OF BASALTS FROM THE SQUID COVE VOLCANICS

	R16	R49	R50	R51	R74	R76	R79	R90	R92	R93
SiO_2	45.4	57.4	45.0	44.8	49.1	47.8	45.7	48.2	49.5	50.2
TiO_2	2.28	2.09	2.12	2.17	2.09	1.54	2.31	2.26	1.28	1.28
Al_2O_3	17.7	12.8	14.0	15.3	14.0	15.5	16.0	15.4	16.1	15.0
Fe_2O_3	3.78	3.59	3.62	3.67	3.59	3.04	3.81	3.76	2.78	2.78
FeO	7.39	1.72	9.49	9.73	8.88	7.61	8.50	8.47	9.27	8.00
MnO	0.13	0.12	0.18	0.18	0.20	0.16	0.20	0.19	0.07	0.10
MgO	7.08	3.88	5.53	4.82	4.56	5.76	6.57	5.76	4.53	4.20
CaO	4.24	9.59	6.59	5.03	6.78	6.48	8.15	4.74	2.74	4.40
Na_2O	3.05	2.34	4.45	5.37	2.42	3.54	3.23	4.58	4.40	4.13
K_2O	2.33	0.33	0.66	0.73	0.26	0.49	0.21	0.23	0.47	0.91
P_2O_5	0.50	0.70	0.43	0.48	0.43	0.26	0.64	0.57	0.28	0.46
L.O.I.	4.50	3.28	6.16	5.23	5.31	5.87	2.79	4.30	5.63	5.69
Total	99.21	98.03	99.30	98.60	98.62	98.90	99.06	99.41	98.09	98.05

	R16	R49	R50	R51	R74	R76	R79	R90	R92	R93
Rb	18	5	14	11	2	6		2	10	20
Sr	315	225	262	268	250	319	360	458	163	276
Y	39	44	32	43	50	37	44	43	20	35
Zr	150	116	115	122	184	101	160	174	83	137
Nb	11	6	8	7	26	9	14	19	8	13
Zn	280	80	111	110	119	99	109	118	108	88
Cu	5	26		3	28	61	18	33	65	20
Ni	264	73	54	85	15	55	64	44	51	43
Ba	734	182	217	135	334	1280	210	213	430	350
V	327	212	340	332	367	356	304	305	450	214
Cr	200	181	95	104	20	107	109	58	92	87

TABLE I (cont.) : MAJOR AND TRACE ELEMENT ANALYSES OF BASALTS FROM THE SQUID COVE VOLCANICS

	R106	R121	R134	R139	R144	R146	R147	R148
SiO_2	47.8	48.1	44.4	50.1	46.9	48.4	47.4	47.6
TiO_2	1.52	1.78	3.37	0.86	1.48	1.45	1.38	1.80
Al_2O_3	16.0	14.7	13.9	16.8	15.9	14.5	16.0	15.3
Fe_2O_3	3.02	3.28	4.87	2.36	2.98	2.95	2.88	3.30
FeO	8.39	8.23	10.81	5.76	10.50	8.41	8.18	8.45
MnO	0.18	0.16	0.17	0.11	0.16	0.19	0.13	0.15
MgO	7.22	5.27	3.22	4.94	2.98	7.47	3.31	5.51
CaO	5.89	4.69	6.00	5.66	5.89	5.77	6.96	6.00
Na_2O	2.76	5.25	5.33	3.89	6.14	4.80	5.38	4.26
K_2O	0.46	0.42	0.10	0.74	0.21	0.30	0.56	0.22
P_2O_5	0.39	0.51	1.42	0.28	0.47	0.39	0.42	0.46
L.O.I.	4.01	4.83	4.15	6.73	3.79	3.38	4.50	4.16
Total	98.58	98.15	98.95	98.88	98.58	98.96	98.00	98.16
Rb	5	5	3	10	4	2	4	0
Sr	247	291	142	390	423	470	318	453
Y	36	35	98	22	31	34	37	39
Zr	127	157	459	109	117	112	116	145
Nb	13	15	43	5	10	9	10	11
Zn	107	98	185	92	136	98	124	112
Cu	19	19	10	2	31	33	26	14
Ni	51	31	5	30	78	100	41	61
Ba	236	185	95	632	332	407	384	296
V	255	241	208	252	239	247	251	307
Cr	105	71		46	174	199	103	72

TABLE II : Microprobe analyses for clinopyroxenes from the Squid Cove volcanics

	1	2	3	4	5	6	7	8	9	10
SiO2	51.26	51.08	50.34	49.97	50.03	50.93	50.34	49.44	50.29	50.12
TiO2	1.99	1.75	2.86	2.41	2.70	1.86	2.00	1.79	2.64	2.73
Al2O3	2.44	2.38	3.63	3.07	3.97	2.47	2.87	2.09	3.07	3.19
Cr2O3	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
FeO	15.07	14.23	12.95	12.35	12.09	13.30	13.13	14.35	12.87	11.74
MnO	.21	.32	.22	.36	.05	.28	.23	.36	.20	.13
MgO	11.25	12.44	12.53	13.27	11.99	12.74	12.13	11.93	12.38	12.43
NiO	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
CaO	18.96	18.47	18.75	19.14	19.79	19.06	19.50	18.92	19.86	19.96
Na2O	.49	.36	.42	.47	.38	.30	.45	.32	.26	.45
K2O	.01	0.00	0.00	0.00	.01	0.00	.01	0.00	.01	0.00
Total	101.68	101.03	101.70	101.04	101.01	100.94	100.66	99.20	101.58	100.75
Si	1.920	1.917	1.869	1.870	1.867	1.909	1.895	1.902	1.875	1.876
Al IV	.080	.083	.131	.130	.133	.091	.105	.095	.125	.124
Al VI	.028	.023	.028	.005	.042	.018	.023	0.000	.010	.017
Ti	.056	.049	.080	.068	.076	.052	.057	.052	.074	.077
Cr	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Fe	.472	.447	.402	.386	.377	.417	.413	.462	.401	.368
Mn	.007	.010	.007	.011	.002	.009	.007	.012	.006	.004
Mg	.628	.696	.693	.740	.667	.712	.681	.684	.688	.694
Ni	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Ca	.761	.743	.746	.767	.791	.765	.787	.780	.793	.801
Na	.036	.026	.030	.034	.027	.022	.033	.024	.019	.033
K	.000	0.000	0.000	0.000	.000	0.000	.000	0.000	.000	0.000
Total	3.988	3.994	3.987	4.012	3.983	3.995	4.001	4.010	3.993	3.993
Ca	40.7	39.2	40.4	40.3	43.1	40.2	41.7	40.3	42.0	42.9
Mg	33.6	36.7	37.5	38.8	36.3	37.4	36.1	35.3	36.4	37.2
Fe+Mn	25.6	24.1	22.1	20.9	20.6	22.4	22.3	24.4	21.6	19.9

DR 22 : 1 - 6 ; DR 50 : 7 - 14 ; DR 79 : 15 - 19 ; DR 106 : 20 - 25 ; DR 146 : 26 - 28

TABLE II (cont.) : Microprobe analyses for clinopyroxenes from the Squid Cove volcanics

	11	12	13	14	15	16	17	18	19	20
SiO2	50.16	48.31	51.15	49.96	51.24	50.62	51.66	53.47	51.31	51.84
TiO2	3.08	3.28	2.19	2.84	1.55	1.52	1.61	.97	1.96	1.43
Al2O3	3.52	4.19	2.68	3.20	2.71	2.58	2.68	1.30	3.20	3.18
Cr2O3	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
FeO	13.09	12.43	13.33	12.32	11.14	11.15	11.25	11.69	11.12	10.74
MnO	.26	.21	.23	.28	.26	.23	.21	.27	.27	.25
MgO	11.89	11.50	12.13	11.58	14.23	14.68	14.77	16.03	14.14	14.95
NiO	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
CaO	19.36	19.94	19.18	19.69	19.27	18.51	18.50	17.45	19.26	18.55
Na2O	.45	.52	.31	.45	.46	.43	.38	.32	.34	.20
K2O	0.00	.01	.01	0.00	0.00	0.00	0.00	0.00	.03	.02
Total	101.81	100.39	101.21	100.32	100.86	99.72	101.06	101.50	101.63	101.16
Si	1.866	1.828	1.911	1.883	1.904	1.901	1.910	1.961	1.891	1.908
Al IV	.134	.172	.089	.117	.096	.099	.090	.039	.109	.092
Al VI	.021	.015	.029	.025	.023	.016	.027	.017	.030	.046
Ti	.086	.093	.062	.081	.043	.043	.045	.027	.054	.040
Cr	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Fe	.407	.393	.416	.388	.346	.350	.348	.359	.343	.331
Mn	.008	.007	.007	.009	.008	.007	.007	.008	.008	.008
Mg	.659	.649	.675	.651	.788	.822	.814	.876	.777	.820
Ni	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Ca	.772	.808	.768	.795	.767	.745	.733	.686	.760	.732
Na	.032	.038	.022	.033	.033	.031	.027	.023	.024	.014
K	0.000	.000	.000	0.000	0.000	0.000	0.000	0.000	.001	.001
Total	3.986	4.004	3.980	3.982	4.010	4.014	4.000	3.996	3.998	3.991
Ca	41.8	43.5	41.1	43.1	40.2	38.7	38.5	35.5	40.3	38.7
Mg	35.7	34.9	36.2	35.3	41.3	42.7	42.8	45.4	41.1	43.4
Fe+Mn	22.5	21.5	22.7	21.6	18.6	18.6	18.6	19.0	18.6	17.9

TABLE II : (cont.) : Microprobe analyses for clinopyroxenes from the Squid Cove volcanics

	21	22	23	24	25	26	27	28
SiO2	50.90	52.54	49.39	52.15	51.09	50.68	50.75	50.59
TiO2	1.37	1.29	1.51	1.28	1.49	1.28	1.77	1.78
Al2O3	2.95	2.58	3.54	2.87	2.82	1.47	3.00	2.96
Cr2O3	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
FeO	12.07	13.03	12.04	10.81	10.99	14.05	11.42	12.51
MnO	.30	.35	.22	.21	.17	.31	.20	.25
MgO	14.79	15.10	15.07	14.74	14.57	14.25	13.54	13.86
NiO	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
CaO	18.40	16.42	18.03	19.28	18.36	16.95	19.22	18.17
Na2O	.21	.23	.29	.22	.38	.32	.28	.14
K2O	.01	.01	0.00	.01	.01	0.00	.01	.01
Total	101.00	101.55	100.09	101.57	99.88	99.31	100.19	100.27
Si	1.892	1.933	1.856	1.915	1.910	1.929	1.900	1.897
AlIV	.108	.067	.144	.085	.090	.066	.100	.103
AlVI	.022	.045	.013	.040	.034	0.000	.033	.028
Ti	.038	.036	.043	.035	.042	.037	.050	.050
Cr	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Fe	.375	.401	.378	.332	.344	.447	.358	.392
Mn	.009	.011	.007	.007	.005	.010	.006	.008
Mg	.820	.828	.844	.807	.812	.809	.756	.775
Ni	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Ca	.733	.647	.726	.759	.735	.691	.771	.730
Na	.015	.016	.021	.016	.028	.024	.020	.010
K	.000	.000	0.000	.000	.000	0.000	.000	.000
Total	4.013	3.984	4.033	3.995	4.000	4.013	3.994	3.993
Ca	37.8	34.3	37.1	39.8	38.8	35.3	40.8	38.3
Mg	42.3	43.9	43.2	42.4	42.8	41.3	40.0	40.7
Fe+Mn	19.9	21.8	19.7	17.8	18.4	23.4	19.2	21.0

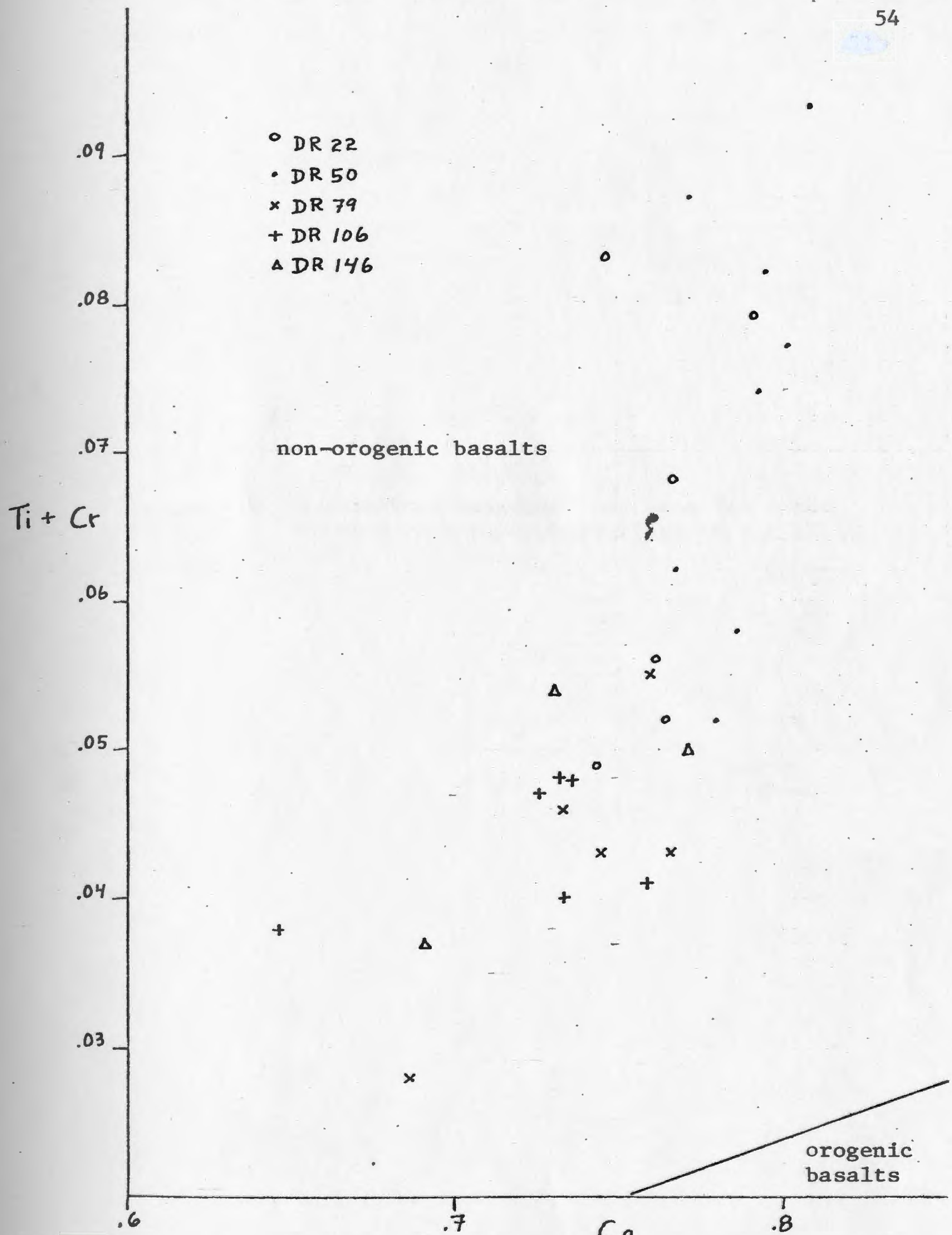

Figure 12: Plot of Ti + Cr versus Ca for pyroxenes from five basalts of the Squid Cove Volcanics, after Leterrier and others (1982).

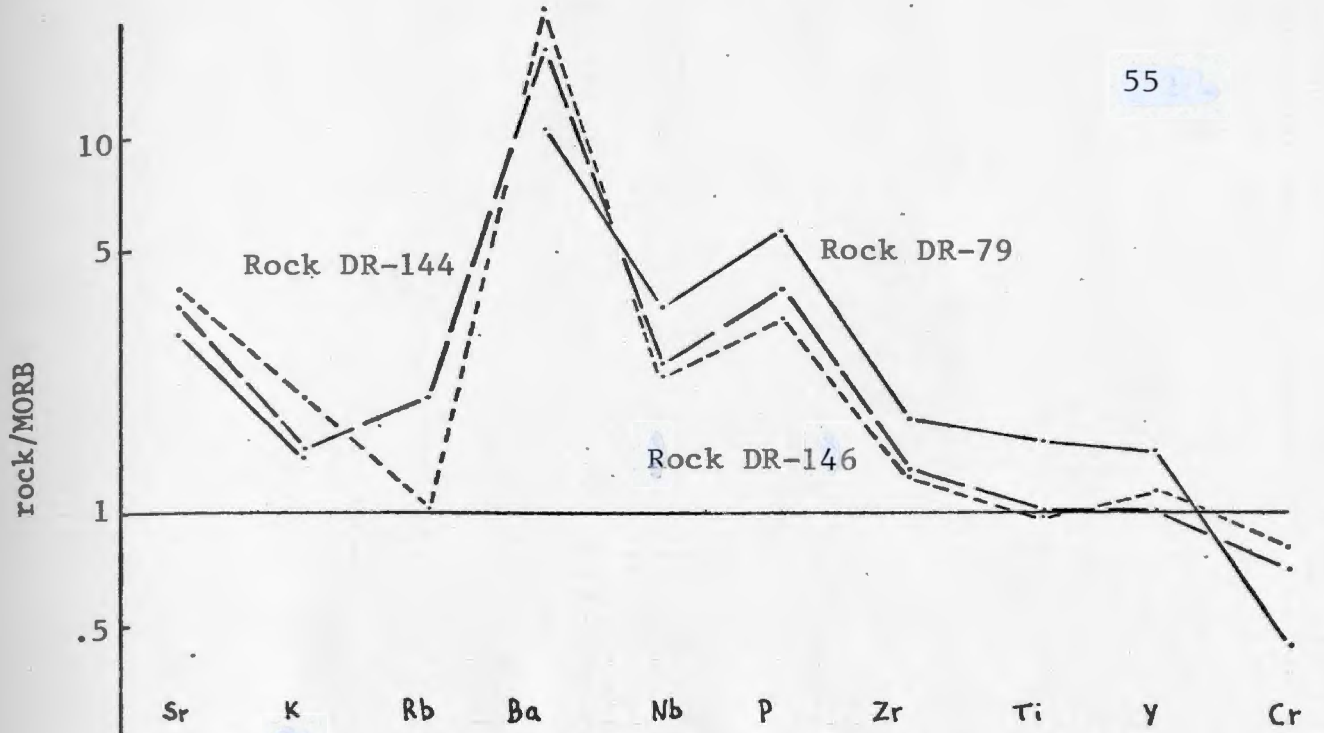

Figure 13 : Geochemical abundance patterns for three Squid Cove basalts, normalized to a typical MORB, after Pearce (1980).

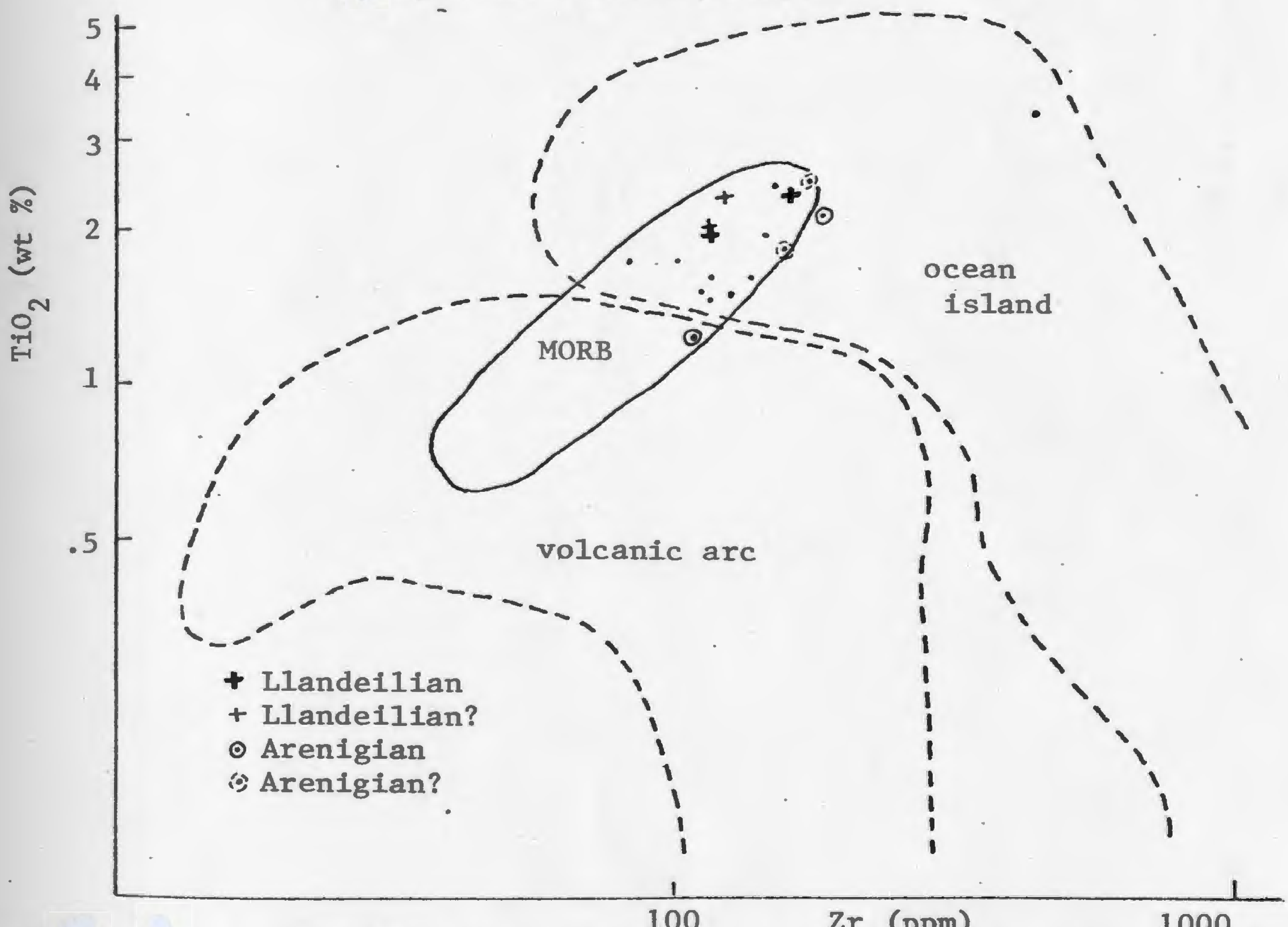

Figure 14 : Ti-Zr covariation diagram for Squid Cove basalts, after Pearce (1980).

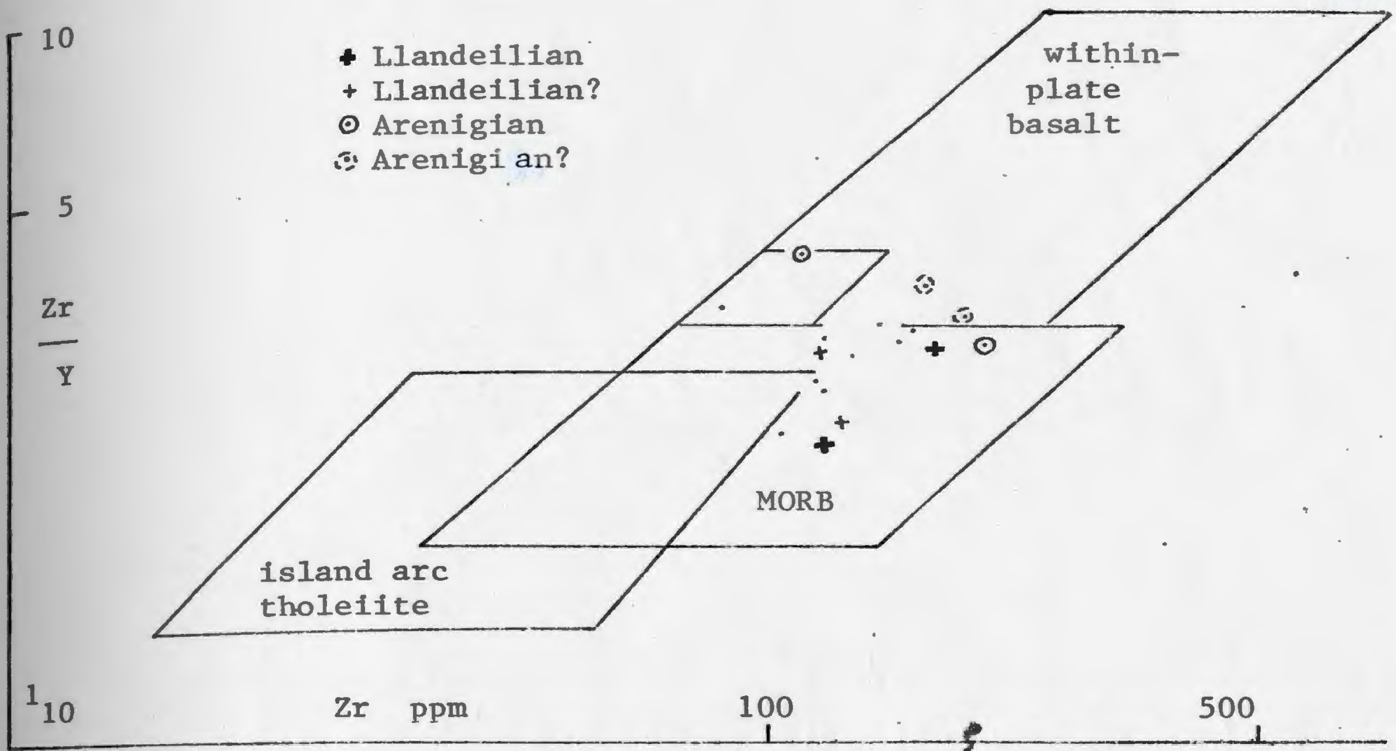

Figure 15: Discriminant diagram of Zr/Y ratio versus Zr for Squid Cove basalts, after Pearce and Norry (1979).

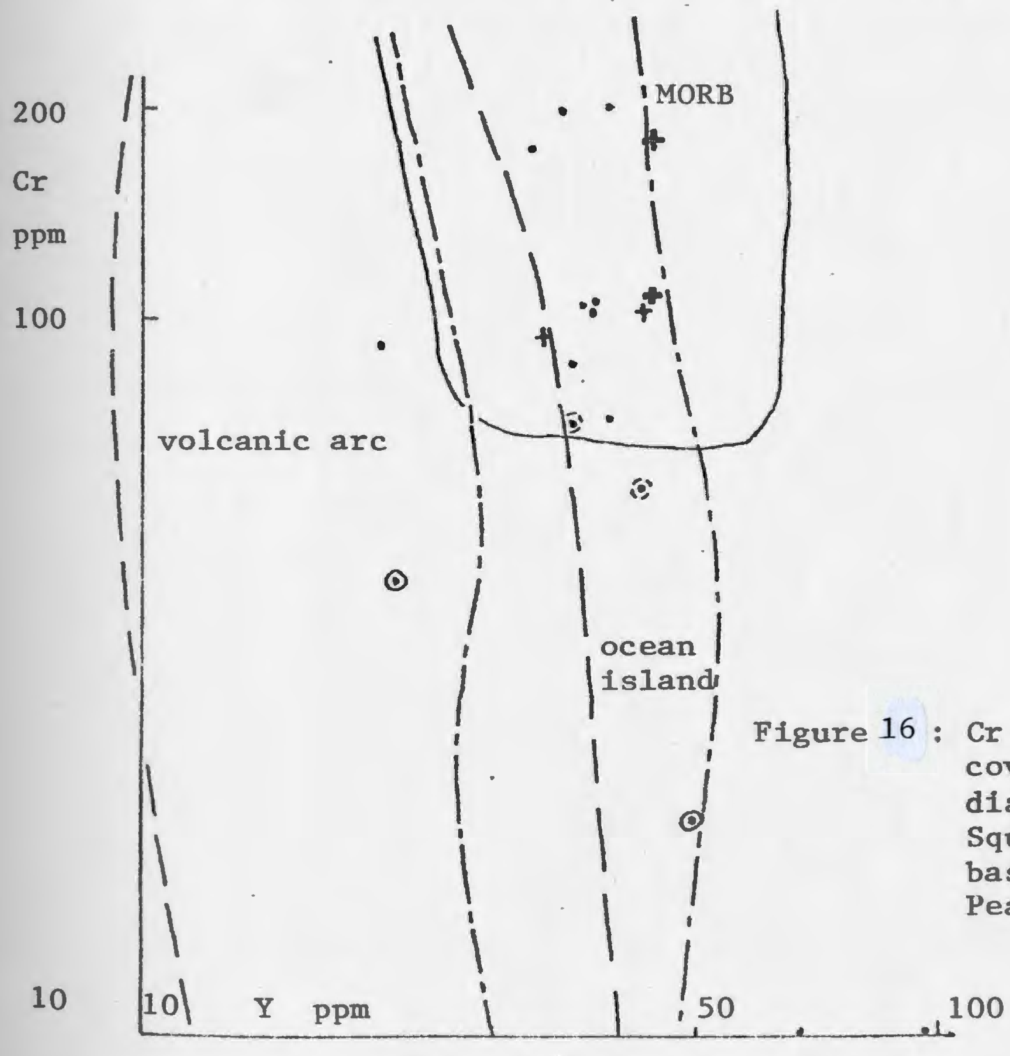

Figure 16 : Cr - Y covariation diagram for Squid Cove basalts, after Pearce (1980).

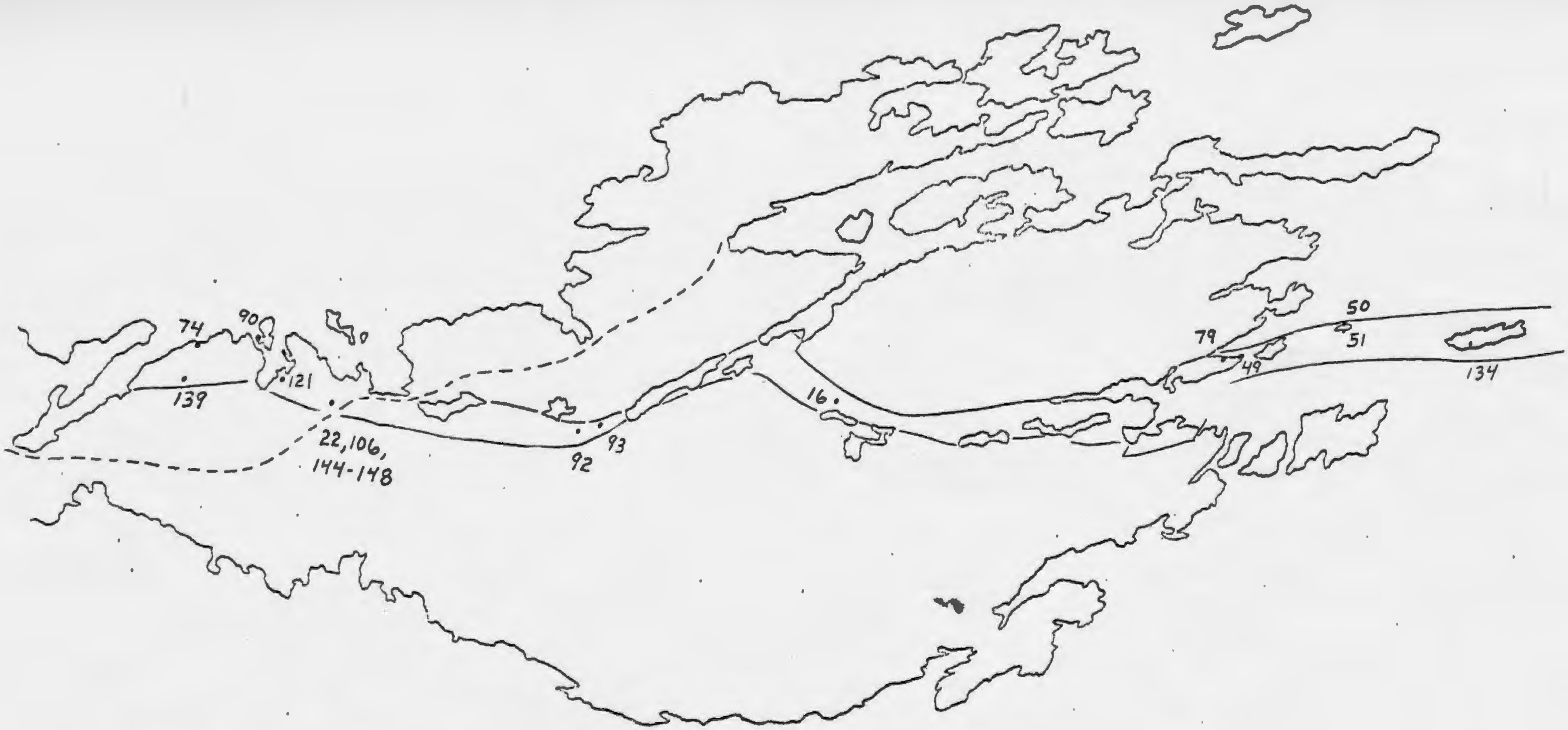

Figure 17: Map showing locations of basalt samples taken for geochemical study.

tholeiites) from a non-orogenic setting.

Dikes probably related to the Squid Cove Volcanics

Intermediate dikes containing distinctive mafic minerals altered to chlorite are not known to intrude units younger than the Squid Cove Volcanics and may be related to them. One such dike is older than a mylonitic shear zone that truncates it in the quarry south of Burnt Cove. If these dikes are related, the proportion of non-mafic rocks in the Squid Cove Volcanics is slightly greater.

A single gray dacite dike, with plagioclase phenocrysts, in limestone (Cobbs Arm?) near the junction of the Twillingate Highway and Fairbanks turn-off resembles the Coaker Porphyry (Kay 1976) of the Dunnage Melange. However, the Coaker Porphyry has a unique geochemical signature not found in dacite of identical appearance on New World Island (Brenna Lorenz, personal communication, 1983).

A dacite body that extends from Virgin Arm to Fairbanks West is the most persistent distinctive unit within the Squid Cove Volcanics. It measures about 1 km by 10 to 100 metres across. It is interpreted to be a dike rather than a flow or dome because it truncates stylolites in limestone at a low angle along its northern contact. The dacite is massive and gray, in places with scattered minute white feldspars. It weathers tan and forms very resistant barren outcrops. Weathered surfaces, locally exhibit an intricate microbrecciated texture with delicate stick-like fragments (Plate 15). Also, folded flow laminae are present. It has been extensively altered, consisting of a very fine-grained mosaic of radiating prehnite orbs and scattered patches of epidote or pumpellyite. Along Virgin Arm, disseminated pyrite has extensively stained the outcrop.

Age of the Squid Cove Volcanics

Fossils occur in volcaniclastic rocks of the Squid Cove Volcanics. They have been intensively studied, and the Squid Cove Volcanics is one of the best dated volcanic units in central Newfoundland.

The oldest fossils are from outside the map area in the correlative Summerford Group (Horne 1970) on southwestern New World Island. They are ellesmeroceratids of early Canadian or Tremadocian age (Kay 1967). Trilobites from the same rocks support this age determination (H.B.Whittington, personal communication, in

Plate 15: Dacite dike along Virgin Arm. Note intricate texture.

Horne and Helwig 1969).

Several tuffaceous horizons along Virgin Arm and near Fairbanks East have yielded trilobites (Dean 1973) and brachiopods (Neuman 1976) of late Arenigian or early Llanvirnian age.

The top part of the Squid Cove Volcanics is late Llandeilian based on trilobites near Squid Cove (Dean 1971) and conodonts in the overlying Cobbs Arm Limestone (Bergstrom and others 1974; Fahraeus and Hunter 1981).

Volcanic rocks included in the Squid Cove Volcanics therefore have an age range of at least 20 million years, yet the oldest and youngest fossiliferous rocks are all lithologically similar.

Squid Cove basalts sampled for geochemical studies include rocks as old as Arenigian-Early Llanvirnian and as young as Late Llandeilian. Most of the samples are too far removed from occurrences of dated fossils to reliably infer their ages. However, the ages of four basalts are known and the ages of four more basalts can be assumed with some confidence. These are indicated on the trace element plots (Figs. 12, 13, and 14). The younger basalts are somewhat more mafic than the older basalts (less SiO2, more Ni and Cr) and fall strictly within the MORB fields. The older basalts plot on the periphery or outside of the MORB fields.

Correlation

The Squid ~~Cove~~ Volcanics spans approximately the same age range as do most of the marine volcanic groups of central (and western) Newfoundland. It has been included in the pre-Caradocian arc of Dean (1978) along with the Moretons Harbour Group, Lower and Middle Exploits Group, Victoria Lake Group, and many others.

Volcanic groups of the Roberts Arm Belt, including the Ordovician Herring Neck Group (Williams and others 1976) and undated Chanceport, Cottrels Cove, Roberts Arm, and Buchans Groups, may also correlate with the Squid Cove Volcanics (e.g. Nelson 1981).

Locally, the Clarkes Cove Volcanics about 1 km northwest of the New World Island Complex correlates with the Squid Cove Volcanics. The Squid Cove Volcanics and volcanic rocks in the Dunnage Melange several kilometres to the southeast of the New World Island Complex were both included in the same map unit 4 by Williams (1963). The Dunnage Melange also contains red shale like that in the Squid Cove Volcanics (Hibbard and Williams 1979; Jacobi 1983). The Dunnage Melange itself has been interpreted as a pre-Caradocian olistostrome. If this interpretation is correct, then it represents a basinal equivalent of the predominantly shallow water (see next section) Squid Cove Volcanics. Further discussion of relationships among the Squid Cove Volcanics, New World Island Complex, and Dunnage Melange can be found in the concluding chapter.

Facies of the Squid Cove Volcanics

Pillow basalts and red shale in the Squid Cove Volcanics suggest an assemblage deposited in deep water. However, most of the Squid Cove Volcanics and the overlying Cobbs Arm Limestone (see next section for lithologic description) contain features indicating that they accumulated in relatively shallow waters, e.g. oxidized basalts with large amygdules; abundant fossils, some of which are restricted in their depth range (Fahraeus and Hunter 1981); abundant calcareous material indicating deposition above the carbonate compensation depth; sedimentary structures and textures such as cross laminations, well sorted crinoid grainstones, and rounded pebble conglomerates indicating active currents and turbulent high energy waters; and reported laterites

(Horne 1968).

Within the map area, abundant pyroclastic rocks in the west suggest close proximity to a center of explosive eruption; the proportion of limestone is greater in the east suggesting more extensive development of calcareous shoals.

Tectonic setting of the Squid Cove Volcanics

The Squid Cove Volcanics are disconnected from their basement and/or plutonic roots. Their tectonic setting must be inferred from their petrochemistry, facies, eruptive style, ages, stratigraphic position, and correlation with better known rocks.

The Squid Cove Volcanics were surely erupted within an ocean basin. Nearby volcanic groups of the same age either overlie ophiolite or are themselves the upper level of ophiolite. The Causeway Diorite phase of the Coaker Porphyry in Dildo Run contains ultramafic xenoliths indicating an ophiolitic substrate (Hibbard and Williams 1979). The Squid Cove Volcanics is not bimodal, and the lack of abundant silicic material also precludes a sialic source.

The Squid Cove Volcanics are tholeiitic with a much smaller proportion of dacite and rhyolite than the calc-alkaline suite typical of modern island arcs. Geochemically, they compare well with non-orogenic tholeiites from mid-ocean ridges and also from ocean islands; they do not compare well with island arc tholeiites.

The Squid Cove Volcanics include mainly rocks of shallow water facies and that locally display explosive eruptive style. Shallow water facies precludes basalts from a typical deep mid-ocean ridge, but not ophiolitic lavas erupted along an anomalous section of ridge (e.g. Iceland) or within a young back-arc basin (as suggested for the Squid Cove Volcanics by Jacobi, 1982). An explosive eruptive style is not characteristic of quiet spreading centers (typical mid-ocean ridge or back-arc basin), but pyroclastic rocks are certainly not unknown from ridges (e.g. Iceland).

Red shale, associated with pillow basalts and autoclastic breccias, is possibly a pelagic facies; it is a candidate for ophiolitic cover. If the red shale is ophiolitic cover and if it occupies a stratigraphic position at the base of the Squid Cove Volcanics (suggested by its distribution at the base of volcanic slices) the overlying Squid Cove Volcanics must be a cover sequence built on ophiolite.

In support of an open ocean (rather than island arc) origin for the Squid Cove Volcanics, correlative volcanic rocks in an identical stratigraphic and structural position and directly along strike to the northeast in the Southern Uplands of Scotland are most commonly mid-ocean ridge or ocean island basalts (Leggett 1979).

Tremadocian volcanic rocks of the Summerford Group and Arenigian-early Llanvirnian rocks and Llandeilian rocks of the Squid Cove Volcanics are all similar. The significance of this wide age range depends on whether the rocks of different ages 1) occur in different structural slices and were erupted in widely separated areas or 2) if all the volcanic rocks were erupted in approximately the same place. If the Squid Cove Volcanics constitute essentially a singl~~e co~~ntinuous stratigraphic section in one structural slice, they cannot be ophiolitic lavas generated at a spreading center.

Squid Cove volcanic activity stopped at approximately the same time as the Taconic arc-continent collision to the west, when the main tract of Iapetus Ocean was finally subducted; this temporal coincidence is commonly cited as evidence favouring an island arc origin for the Squid Cove Volcanics (e.g., Dean 1978).

In summary, geologic constraints do not demand an island arc setting for the Squid Cove Volcanics, the setting most commonly proposed for them. Alternatively, geochemical constraints suggest they are open ocean volcanic rocks.

2.2 Cobbs Arm Limestone

Definition, distribution, and thickness

The Cobbs Arm Limestone overlies the Squid Cove Volcanics. It is presumably overlain by the Rodgers Cove Shale, although there are no exposures where a stratigraphic contact between the two units can be demonstrated.

The name Cobbs Arm Limestone was used by Bergstrom and others (1974) and by Fahraeus and Hunter (1981), but it has never been formally defined. The Cobbs Arm Limestone and Rodgers Cove Shale were included together in the Hillgrade Group by Bergstrom and others (1974). However, the Cobbs Arm Limestone has much more in common with the Squid Cove Volcanics than it has with the Rodgers Cove Shale; for example, limestone occurs throughout the Squid Cove Volcanics, and tuffaceous material is locally abundant in the Cobbs Arm Limestone indicating mutual affinity and a gradational contact. The Hillgrade Group is therefore abandoned.

The Cobbs Arm Limestone occurs in stratigraphic order at only four or five places within the New World Island Complex: Reddicks Cove to Muddy Cove; the south shore of Cobbs Arm; along the road east of Burnt Arm; along the highway next to Burnt Cove; and, although diminished to several beds, nearby in Squid Cove. These largest occurrences are along the north flank of the New World Island Complex. The Cobbs Arm Limestone is nowhere more than 50 m thick. Its discontinuous distribution is due to either lack of primary deposition (Williams 1963) or structural omission.

The Cobbs Arm Limestone was divided into dark lower and light upper members, which were thought to occur in three tectonic repetitions in the quarry south of Cobbs Arm (Kay 1976). Fahraeus and Hunter (1981), finding no faunal support for repetitions, included the six subdivisions in a continuous section.

Lithology

Limestones of the Cobbs Arm Limestone (and Squid Cove Volcanics) display a wide range of compositions and fabrics of primary, diagenetic, and deformational origin.

The main compositional variable is amount of tuffaceous material. A complete gradation exists from tuff and volcanilithic sandstone with rare clastic limy particles through limestone with abundant tuffaceous material to pure limestone. The limestones invariably have a clastic texture where it is not obscured by diagenesis or deformation. Clasts include basaltic sand, whole and fragmented fossils, minor intraclasts, pellets, and, in one example, coarse limestone pebbles. Crinoids are especially common and locally form spectacular massive, well sorted, crinoid grainstones (Plate 16).

The limestones are generally massive with few obvious primary structures. However, cross laminated calcarenite is present on Duck Island, and, along Virgin Arm, interstitial limestone in basaltic breccia contains graded beds.

Locally extensive stylolites indicate pressure solution. In thin section, minute stylolites wind around clean calcite grains. Brecciated fabrics of uncertain origin are common.

Some limestones have not been affected at all by deformation, notably pure crinoid grainstone found in a block near the entrance to Rogers Cove. Other limestones have been coarsely recrystallized to marbles and calcite schists (Plate 61) and mylonitized (Plate 46). The calcite mylonites are well laminated and consist of flattened calcite porphyroclasts in a matrix of ultrafine (4 micron) recrystallized calcite; the relict twinned porphyroclasts have a strong crystallographic preferred orientation whereas the matrix calcite is equant and unoriented.

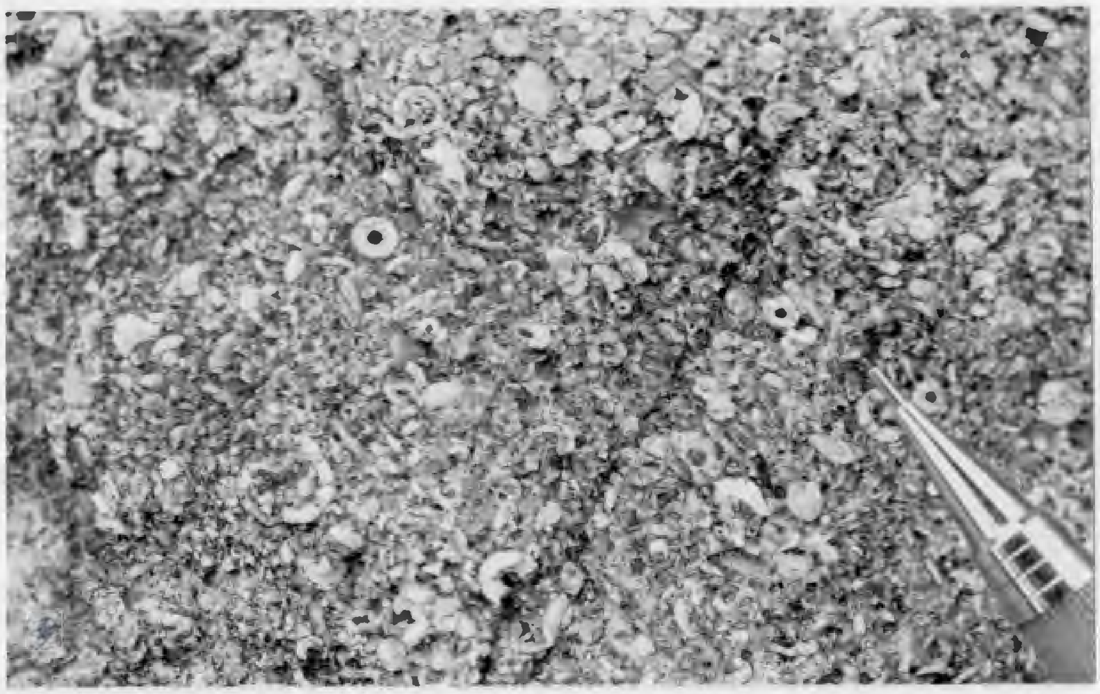

Plate 16: Crinoid grainstone, Cobbs Arm Limestone, near quarry east of entrance to Rogers Cove. Note complete lack of strain.

Phacoidally cleaved limestone resembles sheared basalt (in which lenses of unstrained material are enclosed by an anastomosing network of chlorite).

Age of the Cobbs Arm Limestone

The Cobbs Arm Limestone is well dated by conodonts, which are late Llandeilian (Bergstrom and others 1974; Hunter 1978).

Correlation

Limestone of comparable age to the Cobbs Arm Limestone and in a similar position capping volcanic rocks occurs throughout the Dunnage Zone, e.g. Weirs Pond section in the Davidsville Group to the southeast, Oil Islands section to the northwest, and Victoria Lake Group to the southwest. Limestone in the Boones Point Complex is the same age as the Cobbs Arm Limestone (Nelson 1981). Limestone in the Dunnage Melange has been tentatively correlated with the Cobbs Arm Limestone (Hibbard and Williams 1979).

Significance

Abundant fossils and high energy deposits of crinoid grainstone suggest that the Cobbs Arm Limestone was deposited in relatively shallow water, perhaps as a reef-like structure on volcanic edifices of the Squid Cove Volcanics. Shallow water limestones above a pillow basalt-red shale assemblage in the Squid Cove Volcanics impies a crudely developed shallowing upwards sequence.

The main significance of the Cobbs Arm Limestone is that it marks the late Llandeilian waning of Squid Cove volcanic activity, which is coincident with the emplacement of Taconic allochthons in western Newfoundland. Alternatively, there may be no connection between the two events if the underlying Squid Cove Volcanics is not an arc related to subduction of oceanic crust.

2.3 Rodgers Cove Shale

Name, definition, distribution, and thickness

Bergstrom and others (1974) proposed the name Rodgers Cove Shale for interbedded shale and chert containing graptolites of Caradocian age exposed along the south side of Rogers Cove. It is no more than 30 m thick. Similar rocks occur in many places within the New World Island Complex and also near Little Byrne Cove about 1 km to the northwest.

The Rodgers Cove Shale does not generally occur in continuous stratigraphic sections. It occurs adjacent to Cobbs Arm Limestone in a fault block at its type locality in Rogers Cove and actually on the Cobbs Arm Limestone in a large slab nearby (Plate 35), but there are no examples of a <u>pristine</u> <u>depositional</u> contact between the two units. Dean (1978, p.120) made the same observation. The only known stratigraphic contact is with the <u>overlying</u> Muddy Cove Clastics on Duck Island, where Rodgers Cove black shale and Muddy Cove gray shale and sandstone are interbedded.

Along the north flank of the New World Island Complex, the map pattern of Squid Cove Volcanics, Cobbs Arm Limestone, and Rodgers Cove Shale followed northwestward by the Crow Head Formation suggests a conformable section with only slight structural modification. Details of structural relationships along the northwestern contact of the New World Island Complex are discussed in Chapter III.

Historical background

Williams (1957) included all the shales of the New World Island Complex in one map unit, thereby not distinguishing black shale of Caradocian age from gray shale that is definitely much younger in places (early late Llandoverian).

Williams (1963) and Harris (1966) distinguished Caradocian black shale as a separate map unit, which is the usage followed in this study.

Lithology

Rodgers Cove Shale consists of black, carbonaceous, pyritic shale and chert, which are thinly to very thinly interbedded (Plate 17). Detached slabs of gray, thinly laminated calcareous beds (Plate 18) occur in several places, e.g. Duck Island, Reddicks Cove, and Rogers' Cove. Some sections are mainly shale, notably immediately south of the southernmost volcanic rocks in the New World Island Complex along Virgin Arm. Graptolites are locally common except where it is strongly sheared.

Plate 17: Thinly bedded black siliceous argillite, thin black shale interbeds, Rodgers Cove Shale, near entrance to Rogers Cove on the south shore. Note very thin bed of quartzitic sandstone.

Plate 18: Slab of argillaceous limestone in black chert and shale, Rodgers Cove Shale, Duck Island.

The Rodgers Cove Shale is characteristically sheared in an inhomogeneous fashion, varying from intact blocks of unstrained beds to intensely sheared rock that has no trace of bedding (e.g. along the southeastern margin of the volcanic belt at Virgin Arm and between Tilt Cove and Fairbanks East). The detached calcareous beds in particular are evidence of this style of deformation. Shearing at a high angle to bedding has locally produced breccia (Plate 43). In less deformed outcrops, chevron folds with angular closures have resulted from the strong bedding anisotropy (Harris 1966).

Age and correlation

The Rodgers Cove Shale contains graptolites of Caradocian age (see Dean 1978 for a detailed list of fossil localities).

Caradocian black shale similar to the Rodgers Cove Shale is found elsewhere on New World Island, at Little Byrne Cove (where it is assigned to the Rodgers Cove Shale) and in the Dark Hole Formation (Horne 1970) along the southeastern shoreline of the island. In the Dunnage Mélange, some of the black shale is identical to and thought to correlate with dated occurrences of Caradocian shale elsewhere (James Hibbard, personal communication, 1982). (The Dunnage Melange also includes much older black shale of Tremadocian age.)

Caradocian shale is found elsewhere in the Dunnage Zone in the Lawrence Harbour Shale, Luscombe Formation, Shoal Arm Formation, as far west as Oil Islands in the Parsons Point Formation, and as far east as Weirs Pond in the Davidsville Group.

The base of the Sansom and Point Leamington Graywackes farther west in Notre Dame Bay may be the same age as the upper part of the Rodgers Cove Shale, which suggested to Dean (1978) that pelagic deposition continued for a longer time in eastern areas.

Significance

The Rodgers Cove Shale lies above shallow water limestone of the Cobbs Arm Limestone and below a turbidite section of at least 1 km thickness. Calcareous beds of possible turbidite origin may reflect drowning of the earlier shallow water volcanic and limestone environment. Marked transgression to a deeper water environment may reflect local subsidence or global sea level rise during Caradocian time. The end of Squid Cove volcanic activity, which would have triggered local subsidence, supports the first mechanism whereas the worldwide distribution of

Caradocian black shales indicates a global transgression (Leggett 1978). Alternatively, the Taconic orogenic welt to the west may have contributed to local subsidence, flexing lithosphere downwards to the east; however, distal turbidites of Ashgillian age in the New World Island Complex indicate that the distance between the two areas was probably considerable.

The Rodgers Cove Shale is a significant stratigraphic marker because it is a fossiliferous unit of constant age that exhibits no lateral facies changes (in sharp contrast to the volcanic and clastic rocks in the area). Its present distribution in many places throughout the New World Island Complex and at Little Byrne Cove indicates numerous structural repetitions of a once continuous horizon of uniform lithology and thickness. Its distribution is <u>not</u> explained by numerous black shale horizons in the stratigraphy or by deposition within numerous disconnected basins.

4.5 Muddy Cove Clastics

Name and definition

The name Muddy Cove Clastics is proposed for flysch-type sediments, including gray shale, sandstone, minor conglomerate, and shaly conglomeratic breccia, that occur within the New World Island Complex. The Muddy Cove Clastics conformably overlie the Rodgers Cove Shale on Duck Island and also include the youngest rocks in the New World Island Complex. The Muddy Cove Clastics is represented by many partial sections within the New World Island Complex. None of these sections is much more than 100 m thick, but the initial column that was sampled may have been 1 km or more in thickness. Locally, the Muddy Cove Clastics can be subdivided into map units of mainly gray shale, mainly sandstone, and mainly conglomerate. Individual horizons of shaly conglomeratic breccia are delineated on the 1:1250 map of the Rogers Cove area.

Williams (1957) distinguished shaly and coarse clastic units on his outcrop map. The coarse clastic rocks in the New World Island Complex were not separated from the ones outside it in the Crow Head and Milliners Arm Formations. The shale unit also included the Rodgers Cove Shale.

Williams later (1963) thought that many of the coarse clastic rocks (his map unit 5) were Ordovician and distinct from post-Ordovician flysch because they were apparently interlayered in the Squid Cove Volcanics. He included the section of mainly Silurian shale and lesser sandstone near Rogers Cove in his map unit 10 which also included the Pike Arm Formation (Twenhofel and Schrock 1937).

Harris (1966) included the shaly part of the Muddy Cove Formation in his map unit 4 which was interpreted as the basal Silurian unconformable on Ordovician black shale and limestone. Units of mainly sandstone (his map unit 5) and mainly conglomerate (his map unit 6) were regarded as succesively younger.

McKerrow and Cocks (1978) referred to the mainly shale unit of the Muddy Cove Clastics as Mills Argillite. Mills Argillite was thought to be the matrix of an olistostrome throughout its occurrence in their Big Muddy Cove Group. Sandstones, considered to be olistoliths in most places but locally contemporaneous with the olistostrome, were compared to sandstones of the Milliners Arm Formation.

Distribution of the Muddy Cove Clastics

Muddy Cove Clastics crop out in roughly a dozen places. From west to east, these occurrences include (see Map 1):

1) mainly sandstone along the south flank of the New World

Island Complex near Virgin Arm;

2) mainly sandstone on the peninsula north of Fairbanks East;

3) mainly sandstone in a belt across Tilt Cove and on a small island to the south;

4) sandstone north of a volcanic block 1 km west of Upper Wallet Pond;

5) mainly shale in a belt along the south flank of the New World Island Complex between Burnt Arm and Rogers Cove; shale on the west shore of Upper Wallet Pond is the westernmost known occurrence from this shale belt; sandstones and conglomerates also occur locally;

6) mainly sandstone and shale in two distinct belts on the Cobbs Arm Peninsula (between Cobbs Arm and Rogers Cove);

7) mainly shale along the southeast shore of Rogers Cove between its southwest corner and a fault-bounded Ordovician block to the northeast; breccia occurs in the shale near the fault;

8) mainly shale between the northeast shore of Rogers Cove and the two peninsulas northwest of Joeys Cove; the shale contains diffuse concentrations of breccia and boulder-size and larger inclusions of Ordovician limestone in Rogers Cove; sandstones occur to the northwest near the entrance to Rogers Cove;

9) breccia in the west and south corners of Joeys Cove and on the peninsula to the east, overlying sandstones to the southeast, a thin (1 m) breccia, and mainly shale to the

bottom of Mussel Cove;

10) conglomerate on Tom Cod Shoal in the middle of Cobbs Arm, which can be viewed from an open boat on a calm day;

11) mainly shale in a belt from the tip of Cobbs Arm Peninsula across Quarry Cove Island to the Reddicks Cove Peninsula;

12) mainly shale in four places on Boyds Island; and

13) mainly sandstone at the east end of Duck Island.

Lithology

Sections of mainly sandstone (Plate 19) consist of thinly to thickly interbedded quartzitic graywacke and gray shale. The sandstones are commonly graded and constitute the basal parts of Bouma sequences of AE type. Thick (half metre) sandstone beds occur along Virgin Arm and very thick (one metre) sandstone beds occur at one place between Joeys Cove and Mussel Cove. Sandstones are fossiliferous at the peninsula to the east of Joeys Cove, where brachiopods occur at the base of graded beds.

The structural condition of Muddy Cove sandstones varies considerably. Sandstones are locally poorly bedded (e.g. Virgin Arm (Plate 26)), boudinaged (e.g. Virgin Arm, Fairbanks East (Plate 30)), smeared (e.g. Fairbanks East (Plate 29)), and sheared (e.g. Virgin Arm (Plate

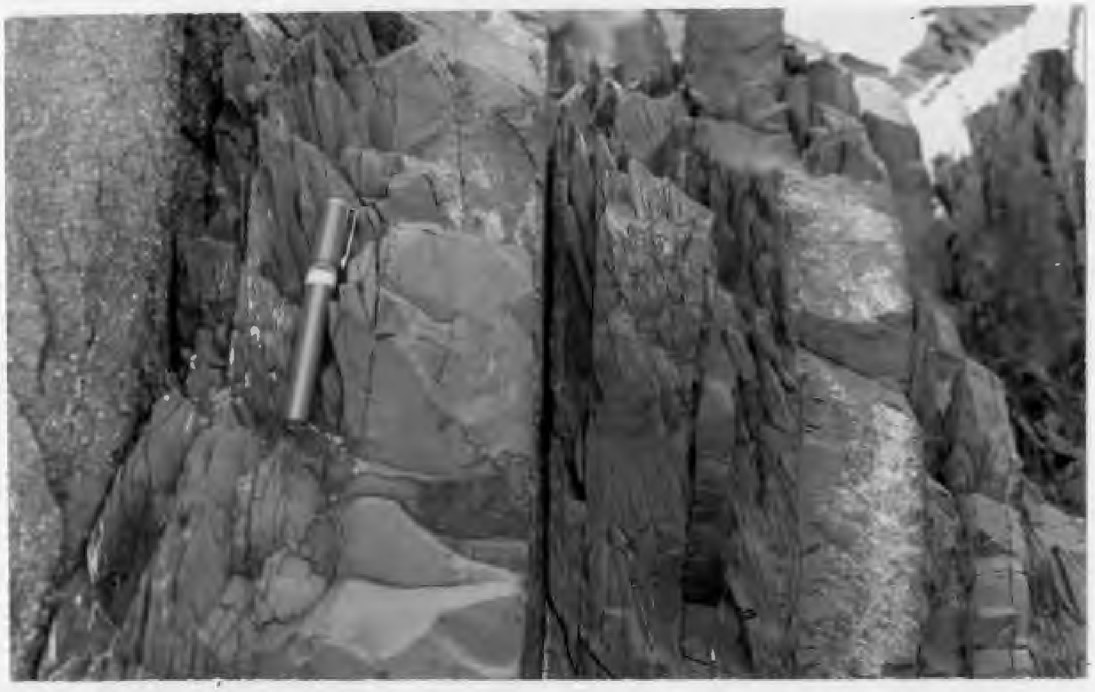

Plate 19: Interbedded sandstone and shale, Muddy Cove Clastics, east of Joeys Cove. Bouma divisions A (graded sandstone) and E (shale) indicate proximal turbidites.

Plate 20: Massive shale, Muddy Cove Clastics shale unit, Mussel Cove. Note three thin beds of quartzitic sandstone, which are upright and which also indicate that the shale is derived from a normally stratified section.

27)).

Conglomerates are polymictic and generally thickly bedded. They are generally unstrained, but a severely deformed conglomerate with wafer-thin pebbles was found in float along the Mills Pond Fault, which bounds the New World Island Complex to the northwest in one place.

Shaly sections consist of massive gray shale and rare thin, graded beds of quartzitic sandstone (Plate 20). The shale is locally fossiliferous, e.g. scattered corals occur in shale along the southeast shore of Rogers Cove and in shale west of Mussel Cove (Plate 21). Oval-shaped clasts of limestone, which locally contain fossils, are either concretions or boudinaged beds. The thin sandstone beds are everywhere discontinuous and have been boudinaged. The shale has well developed slaty cleavage.

Shaly conglomeratic breccias (Plates 22-24) consist generally of a poorly sorted to unsorted assemblage of pebble to boulder-size clasts in shaly matrix. The amount of matrix varies such that most are matrix-supported whereas some are clast-supported like normal conglomerates in the area. They are not internally stratified. Clasts include sandstone, gray chert, black chert, black shale and chert, minor limestone, granite, corals, and brachiopods. The granite and grey chert pebbles are rounded whereas

Plate 21: Silurian coral in shale unit of the Muddy Cove Clastics, east of Joeys Cove. Note that cleavage in the surrounding shale is not developed in the coral composed of more competent calcite; the coral behaved as a nearly rigid body during deformation.

Plate 22: Boulder of graywacke in shaly conglomeratic breccia, Muddy Cove Clastics, Joeys Cove.

black chert and larger fragments of black shale and chert are angular. (For this reason, the term conglomeratic breccia is preferred to pebbly/bouldery mudstone in order to emphasize the contrasting shapes.)

The shaly conglomeratic breccias vary considerably from place to place. On the northeast shore of Rogers Cove, breccia consists mainly of fragments of black shale and limestone and some brachiopods, and has abundant shaly matrix (see Plate 40 in Chapter III). The shaly matrix is continuous with surrounding shale and is not composed of amalgamated shale clasts as was proposed for matrix-supported (but initially framework-supported) conglomerates from the Carmanville area (Paul Williams, personal communication, 1982). One clast of limestone contains a poorly developed, non-penetrative foliation and also some undeformed crinoid columns. In the west corner of Joeys Cove, breccia contains large boulders of Ordovician rocks. In a cliff face near the south corner of Joeys Cove, it contains a large graywacke boulder and has sparse matrix (Plate 22). On the point to the east, it has a high proportion of black shale fragments, a few limestone clasts, and an increasing number of sandstone slabs near its gradational contact with overlying fossiliferous sandstones (Plate 23). A 1 m thick breccia between sections of mainly sandstone and mainly shale to the east contains almost entirely angular fragments of black shale

Plate 23: Shaly conglomeratic breccia, Muddy Cove Clastics, Joeys Cove. Poorly sorted assemblage of angular shale to siltstone fragments and corals in shaly matrix.

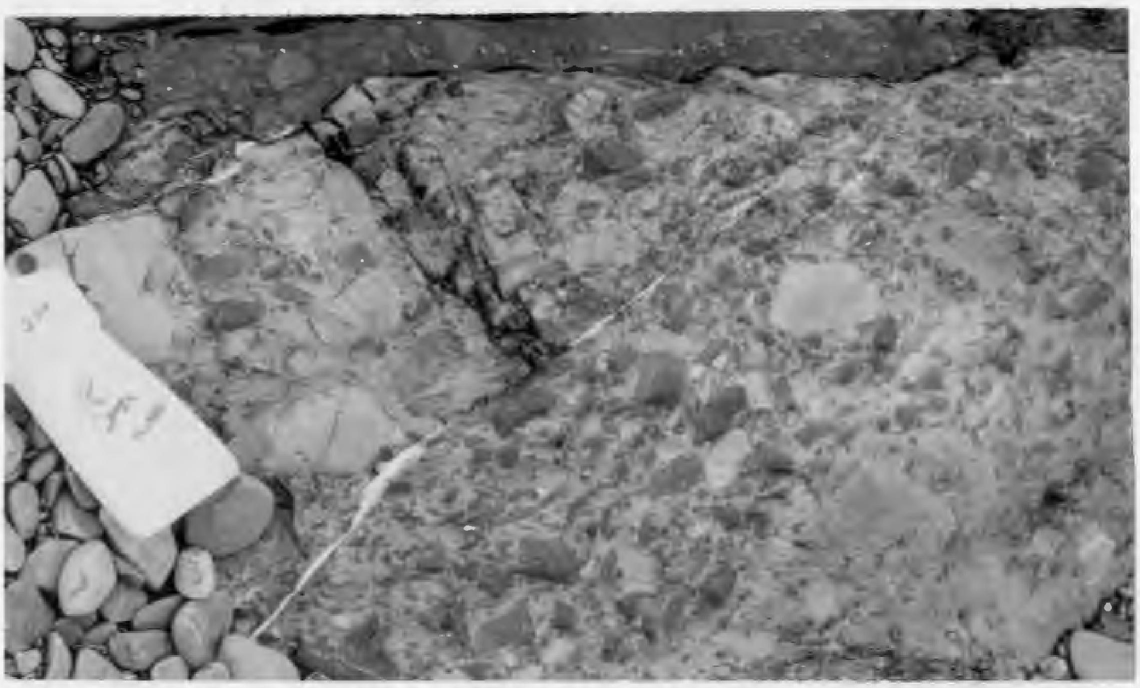

Plate 24: Shaly breccia composed of angular black chert fragments in abundant gray shale matrix of Silurian age, Muddy Cove Clastics, east of Joeys Cove. Interpreted as debris flow deposit.

and has a large proportion of shaly matrix (Plate 24). On the southeast shore of Rogers Cove, several metres to the west of the fault-bounded Ordovician block, breccia contains (oddly) a thin (several cm) horizon of limestone which has inclusions of angular black shale dispersed in it.

Age and correlation

The lower part of the Muddy Cove Clastics is constrained in age by Caradocian graptolites of the Rodgers Cove Shale that lies conformably beneath it on Duck Island. The lower part of the Muddy Cove Clastics correlates with the base of the Milliners Arm Formation and probably (see later sections) the base of the Crow Head Formation.

The age of most Muddy Cove sandstone is only generally known from lithic correlation with dated Upper Ordovician to Silurian sandstones of the Muddy Cove Clastics and Milliners Arm Formation. Sandstones along Virgin Arm enclose pods of black, pyritic shale resembling the Rodgers Cove Shale, which suggests, by the close physical association, that the sandstones are Ordovician and not Silurian. Likewise, Muddy Cove shales on Quarry Cove Island contain streaks of black shale and, on Boyds Island, contain a large inclusion of Rodgers Cove Shale, suggesting that the two shales may be close in the stratigraphy.

Also, Muddy Cove shales, where not fossiliferous, lithologically resemble the unfossiliferous upper portion of the Ordovician Dark Hole Formation (Horne 1970).

Muddy Cove conglomerates are lithologically identical to Silurian conglomerates of the Milliners Arm Formation.

Fossiliferous shales, sandstones, and breccias in the Rogers Cove area are of early late Llandoverian age (McKerrow and Cocks 1978) and are the youngest dated rocks in the New World Island Complex. They are also younger than the youngest dated rocks of the Milliners Arm Formation. The entire section of Muddy Cove Clastics near Rogers Cove was included with the Pike Arm Formation in map unit 10 of Williams (1963); however, fauna of the Pike Arm member of the Crow Head Formation have subsequently been shown to be slightly younger (McKerrow and Cocks 1978). The shale section near Rogers Cove correlates with the Green Cove Formation (McKerrow and Cocks 1978) or Green Cove member of the Crow Head Formation of this study. Fossiliferous sandstones in the Joeys Cove area are lithologically similar to, but somewhat younger than ones in the lower part of the Crow Head Formation. Shaly conglomeratic breccias are not known to occur elsewhere on eastern New World Island, but have been reported from the Boones Point and Sops Head Complexes farther west in Notre Dame Bay (Nelson 1981).

Significance of the Muddy Cove Clastics

The basal contact of the Muddy Cove Clastics on Duck Island is one of the best exposed in the area, and precisely dates the onset of clastic sedimentation as Upper Ordovician.

The Muddy Cove Clastics is a clastic flysch sequence. By analogy with better preserved correlative sections in the Milliners Arm and Crow Head Formations (discussed in later sections), most of the Muddy Cove Clastics represents part of a submarine fan fed by eroding highlands to the west.

The youngest shaly sections of the Muddy Cove Clastics presumably overlie coarser sandstones and conglomerates. This inferred stratigraphic sequence from coarse to fine sediments implies that the basin became closed to the entry of coarse clastics. The controlling factors are uncertain, but perhaps they were structural.

Breccias interpreted as sediments

Shaly conglomeratic breccias in the youngest sections of the Muddy Cove Clastics are chaotic matrix-supported rocks or diamictites. Diamictites in general are interpreted as (e.g., Flint 1957) :

1) subaerial and subaqueous debris flow deposits in which clasts were supported by the strength of the matrix;

2) normal conglomerates which, following deposition, were mixed with underlying mud;

3) normal framework-supported conglomerates in which shale clasts were squashed to form matrix during deformation (Paul Williams, personal communication, 1981);

4) fine grained sediment with glacial dropstones;

5) till formed by shearing at the base of a moving glacier;

6) shear zones related to movement between crustal fault blocks; including

6a) ones that have been stripped from competent blocks and incorporated within adjacent shale; and

7) the deposits of mud volcanoes or their frozen conduits.

It is crucial to distinguish between the interpretations of Muddy Cove breccias as sediments or shear zones. The distinction is not obvious because many of the available criteria are non-diagnostic, e.g.:

1) although breccias are concordant with stratified sediments in two places between Joeys Cove and Mussel Cove, this criterion does not rule out a bedding plane shear zone;

2) the breccia contains a polymictic assemblage of clasts, but so do many shear zones;

3) the breccias contain fossils, but these are composed of calcite which is known to be competent (Plate 21); they

could behave as rigid bodies in the matrix of ductile shale;

4) the breccia contains fragments of incompetent black shale; but similar fragments in shear zones are relict beds preserved due to the very nature of inhomogeneous shear.

The most convincing evidence suggesting the breccias are sediments includes:

1) their gradation with normal conglomerates at the expense of some shaly matrix; and

2) cleavage is not more intensely developed in breccias than in surrounding rocks. The breccias are most similar to rocks, including pebbly and bouldery mudstones, interpreted as the deposits of subaqueous debris flows (e.g. Nelson, 1981).

Tectonic significance of breccias

The polymictic clast assemblage of the breccias is bimodal. In addition to rounded granitic pebbles that have had a history of sedimentary rounding, the breccias include angular fragments of non-durable black shale. Clasts of the second type indicate an additional source area that was exposed nearby. Black shale fragments are identical to the Rodgers Cove Shale, and clasts of limestone and basalt resemble the Cobbs Arm Limestone and Squid Cove basalts.

Shaly conglomeratic breccias seem therefore to have sampled the local stratigraphic section, which may be rooted as close as the peninsulas northwest of Joeys Cove (Map 2, locations 6 and 7) and definitely to the northwest of Rogers Cove (although the source area and deposit may have been separated by a greater distance prior to movement along intervening faults). The breccias may locally have been deposited directly at fault scarps (see Chapter III, section 3.8.1 for interpretation of the gradational relationship between breccia and the sheared margin of a limestone slab).

The source area of Ordovician rocks could not have been penetratively deformed in the Silurian because Ordovician rocks are not now penetratively deformed. A clast of limestone contains a non-penetrative foliation alongside undeformed crinoid columns and suggests that the source area was also inhomogeneously deformed in the Silurian prior to the end of deposition. An inferred unconformity above this source area would be near the top of the local stratigraphic section as opposed to at its base (Kay and Williams 1963; Harris 1966).

CHAPTER III

STRUCTURAL RELATIONSHIPS WITHIN THE NEW WORLD ISLAND COMPLEX

The chaotic character of the New World Island Complex distinguishes it as a mapable rock body. It contrasts sharply with stratified sections that are relatively unfaulted in the adjacent Crow Head and Milliners Arm Formations. The New World Island Complex is subdivided into a mosaic of blocks and clasts of diverse geometries and origins.

Within the New World Island Complex, blocks and clasts range considerably in size and shape, from

1) small fragments of Rodgers Cove Shale in sedimentary breccias to

2) imbricated slices of Squid Cove Volcanics more than 1 km long.

Contacts between these elements also vary considerably, e.g.

1) sharp contacts bound xenoliths of Cobbs Arm Limestone engulfed in intrusions of Muddy Cove shale;

2) calcite mylonites are developed between blocks of unstrained limestone; and

3) clean, brittle faults locally separate tectonic slices (stratigraphic contacts within blocks were described in the previous chapter). In summary, the New World Island Complex varies from a belt of imbricated fault slices to a

melange of volcanic and limestone blocks and sedimentary matrix; the melange is polygenetic, including sedimentary and tectonic components.

Structural relationships within the New World Island Complex and the nature of its contacts with adjacent units are discussed for individual segments from west to east. Particular attention is given to relationships between tectonic elements that constitute the New World Island Complex and structures (pre-cleavage folds, climactic folds, cleavage, various faults) that are more widely recognized in all the rock groups of eastern New World Island.

3.1 Virgin Arm

Along Virgin Arm (Map 1), the New World Island Complex includes a thick slice of Squid Cove Volcanics north of Muddy Cove sandstone and shale. Mylonite occurs at the contact of the volcanic rocks along with a lens of sheared black shale immediately to the south, which is assigned to the Rodgers Cove Shale. These units collectively lie north of Silurian conglomerate of the Milliners Arm Formation.

Beds in the Milliners Arm Formation, Muddy Cove Clastics, and Squid Cove Volcanics face northwest. The presence of older rocks to the north indicates that the section must be imbricated. Beds are moderately to strongly overturned in the New World Island Complex, compared to slightly overturned in the Milliners Arm Formation; this geometry indicates that northerly fault slices moved relatively upward. Cleavage dips consistently less than bedding, which further emphasizes that the distribution of units is controlled by faults rather than folds.

The Squid Cove Volcanics are inhomogeneously strained. Local preservation of primary features, such as interstices in basalt flows filled by calcite (Plate 7), indicates little deformation in places. Elsewhere, fossils from tuffs are tectonically distorted (Dean 1974; Neuman 1976).

Intense localized strain in volcanic rocks about fifty meters north of Fairbanks West is indicated by strongly sheared and flattened pillow lavas (Plate 25).

A body of dacite is the most continuous lithic unit in the slice of Squid Cove Volcanics along Virgin Arm. Its northern contact cuts obliquely across a stylolitic foliation in limestone. The dacite body may be a dike rather than a flow or dome, but it is probably related to the Squid Cove Volcanics.

The mylonite that occurs at the base of the Squid Cove Volcanics section is a grey massive rock consisting of alternating thin lenticles rich in carbonate and rich in chlorite and murky material. The mylonitic fabric is partly overprinted by growth of calcite. In the coarse lenticles, quartz and feldspar grains, which are attenuated, suggest a clastic (volcaniclastic?) protolith. The primary lenticular fabric is folded on a small scale and occurs in domains bounded by microfaults that are parallel to the main fabric.

The southerly section of Muddy Cove Clastics consists mainly of sandstone and grey shale. Bedding is partially obliterated (Plate 26) to sheared (Plate 27), and sandstone beds are locally boudinaged. A folded sandstone bed diminishes in thickness from about 30 cm to nothing around

Plate 25: Sheared basalt, Squid Cove Volcanics, north of Fairbanks West along Virgin Arm. Remnants of pillows? in matrix of chlorite schist.

Plate 26: Partially obliterated bedding in thick bedded sandstones, Muddy Cove Clastics, Virgin Arm.

Plate 27: Sheared sandstone and minor shale, Muddy Cove Clastics, Virgin Arm. Note characteristic anastomosing pattern of shear surfaces.

the hinge of a fold (Plate 28) which formed before the sediment was lithified. Two thin pods of black, pyritic shale, along strike from each other, are enclosed within grey shale and sandstone. The contacts are sharp, but bedding is not well preserved in either unit. The black shale resembles and is tentatively assigned to the Rodgers Cove Shale. The grey shale may not have been interbedded with the enclosed black shale, but the close association suggests the sandstone may also be Ordovician.

The location of the contact between the New World Island Complex and the Milliners Arm Formation is not obvious along Virgin Arm. Along strike, however, basaltic flow breccias of the Squid Cove Volcanics lie immediately north of north-facing Silurian conglomerate of the Milliners Arm Formation. Horne (1976) drew only one major fault in this area, the Cobbs Arm Fault, which was offset by a cross fault; however, three longitudinal faults that splay into one another must be inferred here because some Muddy Cove sandstones lie immediately north of the basaltic flow breccias mentioned above.

Undeformed dikes of felsic quartz-phyric rhyolite

Plate 28: Attenuated and folded boudin of sandstone in shale, Muddy Cove Clastics, Virgin Arm. Fold hinge is slightly above center of photograph. Extreme attenuation of the sandstone bed without breakage suggests that it was unlithified during deformation. Note small (1 cm) clast of sandstone above left tip of pencil, which is probably another isolated boudin.

intrude both Squid Cove Volcanics and Muddy Cove clastics.

3.2 Tilt Cove

Tilt Cove (Map 1) occurs at a sharp flexure in the New World Island Complex. A minor cross fault from Fairbanks East southwestward serves as a convenient boundary between this domain and the one along Virgin Arm.

Squid Cove Volcanics occur in three belts between the bottom of Tilt Cove and the peninsula north of Fairbanks East and are separated by outcrops of black shale (Rodgers Cove) and sandstone and shale (Muddy Cove). To the east, a belt of sandstone and shale (Muddy Cove) extends from the southeast corner of Tilt Cove Island across to the east side of Tilt Cove and separates northern and southern belts of Squid Cove Volcanics.

The occurrence of Rodgers Cove Shale in the section of Squid Cove Volcanics northwest of Tilt Cove implies repetition of the volcanic rocks. The extensions of this fault are uncertain as only one outcrop of younger rocks was found. Horne (1968) extrapolated the black shale unit southwestward to Virgin Arm, although he viewed it as interbedded in the volcanic rocks.

Beds in the two belts of sandstone and shale face north. Williams (1963) assigned these rocks to his map unit 5, which he thought was interbedded in the volcanic rocks. The strong lithologic resemblance of these rocks to nearby post-Caradocian sandstone and shale warrants their assignment to a younger unit. The volcanic rocks must therefore be imbricated here also. Again, as along Virgin Arm, the sense of imbrication, indicated by strongly overturned beds in the New World Island Complex compared to slightly overturned beds in the Milliners Arm Formation, suggests that northerly fault slices moved relatively upwards.

Within the sandstone and shale section at the point north of Fairbanks East, sandstone beds are boudinaged (Plate 29) and bedding is smeared locally (Plate 30). The volcanic block to the north is separated from the sandstone and shale by a steeply south-dipping planar fault.

Along the east side of Tilt Cove, red shale containing dispersed inclusions of basaltic material occurs at the northern contact of the sandstone-shale belt. The basaltic inclusions are broken along chloritic surfaces, and the red shale represents a shear zone separating the Muddy Cove Clastics and Squid Cove Volcanics.

Muddy Cove Clastics on a small island in Tilt Cove to the south of the main trans-Tilt Cove belt of

Plate 29: Boudin of sandstone in shale, Muddy Cove Clastics, north of Fairbanks East. Note vertical bedding in boudin at right angles to its long axis.

Plate 30: Smeared sandstone and shale, Muddy Cove Clastics, north of Fairbanks East.

sandstone-shale face east. They may be a continuation of the trans-Tilt Cove belt. They strike southwest towards the southern contact of the New World Island Complex with the Milliners Arm Formation. They are the only known east-facing beds in the area, and, significantly, cleavage dips more steeply than bedding. The sandstone beds may represent an F2 fold limb isolated in the southern flank of the New World Island Complex. A small volcanic block occurs at the north tip of the island.

The Cobbs Arm Fault marks the southern contact of the New World Island Complex. It strikes northeast from Virgin Arm directly towards Tilt Cove. A prominent rectilinear airphoto lineament occurs <u>within</u> volcanic rocks parallel to the contact, but the actual Cobbs Arm Fault is less conspicuous. Silurian Milliners Arm conglomerate faces north several tens of meters to the south.

The Cobbs Arm Fault is exposed in the bottom of Tilt Cove (Plate 31). Cherty mylonite, with a delicate, wispy fabric, contains rhombohedral inclusions of limestone and black chert. The mylonite protolith is possibly sandstone. An adjacent block of basalt may be another larger clast in the fault zone.

3.3 <u>Squid Cove and Burnt Coves</u>

Plate 31: Rhombohedral clast of limestone in matrix of cherty textured mylonite, Cobbs Arm Fault, bottom of Tilt Cove.

The New World Island Complex south of Squid Cove and north of Tilt Cove Pond is composed mainly of Squid Cove Volcanics (Map 1). Sheared black shale (Rodgers Cove) and limestone (Cobbs Arm) at the junction of the Twillingate Highway and the road to Tilt Cove indicate internal complication. Along Twillingate Highway, a band of calcite mylonite truncates a large dike (Plate 32) and implies that Squid Cove Volcanics are imbricated across it.

The calcite mylonite crops out in the roadcut on the east side of the Twillingate Highway about 50 m south of the junction with the road to Tilt Cove (Plate 33) and again at the entrance to the quarry about 50 m farther south in the roadcut on the south side. It is prominently laminated and dips moderately southeast. Relict calcite crystals are strongly flattened and have a preferred crystallographic orientation in the plane of the mesoscopic foliation. They are enclosed in a matrix of ultrafine (4 micron) equant calcite that does not have an obvious preferred crystallographic orientation. Basalt along strike of this zone of shearing is also strongly sheared locally and red shale containing tectonic admixtures of basalt occurs in the vicinity. The mylonitic foliation is locally folded about east-plunging axes in the northern outcrop (Plate 34); the antiform of the fold pair lies north of the synform, which is the most common asymmetry of F2 folds in the area. The calcite mylonite may actually be

Plate 32: Dike of intermediate composition in Squid Cove basalts, quarry along Twillingate Highway south of Burnt Cove. A fault, indicated by a belt of calcite mylonite and sheared basalt extending from the quarry entrance through the outcrop on the far side of the road, truncates the dike to the right.

Plate 33: Band of calcite mylonite in roadcut south of Burnt Cove, east side of road opposite turnoff to Tilt Cove. Foliation dips southeast.

Plate 34: Calcite mylonite, Twillingate Highway. The mylonitic lamination is folded with antiform northwest of synform asymmetry like that of climactic (F2) folds nearby.

a reduced equivalent of the Cobbs Arm Limestone rather than a sheared limestone interbedded in the Squid Cove Volcanics.

Volcanic rocks east of Tilt Cove are dissected by prominent linear scarps that trend at a high angle to the trend of the New World Island Complex. These "volcanic cross faults" are confined to the New World Island Complex and possibly to the Squid Cove Volcanics within the complex. If so, they may be early structures unrelated to later deformation. If not, they represent cross faults that are conjugate with the main longitudinal faults of the area.

Along the northern contact of the New World Island Complex between Squid Cove and Burnt Cove, the Squid Cove Volcanics, Cobbs Arm Limestone, and Rodgers Cove Shale occur in relatively undisturbed stratigraphic order south of the Crow Head Formation. Cobbs Arm Limestone crops out for almost 1 km southeast of Burnt Cove. It is locally phacoidally cleaved and asymmetrically folded on a small scale with Z-asymmetry (looking northeast). At Squid Cove, the Cobbs Arm Limestone is represented by less than 2 m of limestone. Rodgers Cove Shale several meters to the north on the far side of an unexposed contact is strongly deformed, and the reduced thickness of the Cobbs Arm Limestone may be due to structural omission. The Rodgers

Cove Shale extends northeastward towards Burnt Cove and an outcrop at its northeast end, which is now covered by road material.

The only exposed contact between Rodgers Cove Shale and Crow Head Formation is on a small island in Squid Cove. Here, the Rodgers Cove Shale contains thin, tan-weathering sandy beds that are east-facing based on grading and lobate sole marks. The Crow Head Formation here consists of brown-weathering sandstone, shale, and limestone concretions, with bedding obscured by cleavage except in the limestone concretions. Lithologies of the two formations are delicately interfoliated along the contact, which is a fault based on the truncated beds. The overall configuration can be summarized as smeared and is most reasonably interpreted as a conformable contact modified by minor faulting under conditions during which the shales behaved ductilely and the sandstone beds and limestone concretions behaved more brittlely. Horne (1976) interpreted the belt of deformation at the base of the Crow Head Formation as having formed penecontemporaneously with deposition, but his criteria are questionable.

Westward, in the bottom of Squid Cove, a small outcrop of Rodgers Cove Shale, containing graptolites, was found bounded by a cross fault with left-lateral displacement.

Farther westward, Cobbs Arm (?) Limestone on an island just offshore is strongly foliated in a narrow zone. An island still farther offshore is composed of pyroclastic breccia of the Squid Cove Volcanics. Its position remote from the main outcrop belt of the New World Island Complex is anomalous. Although topographically reminiscent of a block, no contacts are exposed. Complications must nevertheless be present along this segment of the northern contact of the New World Island Complex.

3.4 Twillingate Highway to Wallet Pond

Squid Cove Volcanics crop out continuously between Twillingate Highway and Wallet Pond (Map 1). There is a fairly high percentage of outcrop. No rocks of definitely younger age are known, and the belt is apparently unbroken except by several cross faults that are confined to the New World Island Complex; red shale occurs along the eastermost cross fault.

Along the southern contact of the New World Island Complex are two slices of Squid Cove Volcanics separated from the main belt of Squid Cove Volcanics by Rodgers Cove black shale (western slice) and Muddy Cove sandstone (eastern slice). Contacts are not exposed. Foliated limestone occurs within the volcanic belt just north of the southern contact of the New World Island Complex just east of the Twillingate Highway. Its age is unknown; if it is the Cobbs Arm Limestone rather than limestone interbedded in the Squid Cove Volcanics, then volcanic rocks adjacent to the south constitute a third slice along this segment of the southern margin of the New World Island Complex. The slices may be olistoliths, but a more likely interpretation is that they are fault slices akin to clasts in the mylonitic Cobbs Arm fault zone at Tilt Cove.

The southern contact in general, drawn at the base of resistant volcanic hillsides,is nowhere exposed; as drawn, it is not a rectilinear feature as shown on previous maps.

The northern contact of the New World Island Complex is covered and is the site of two ponds. It is inferred to be a minor fault because of apparent stratigraphic omission of the Cobbs Arm Limestone and Rodgers Cove Shale and its rectilinear nature.

3.5 Wallet Pond to Burnt Arm

The Burnt Arm Fault displaces the New World Island Complex about 2 km in a left-lateral sense from one end of Wallet Pond to the other. It is not a clean fault as depicted on larger scale maps (e.g. Kay 1976) but Squid Cove Volcanics are strung out along it.

Squid Cove Volcanics occur twice-repeated in fault slices as indicated by outcrops of Rodgers Cove Shale both south and north of Wallet Pond. This imbrication presumably predates the Burnt Arm Fault.

Squid Cove Volcanics between Wallet Pond and Burnt Arm form a resistant hill that is shaped like a large lozenge, thick in the middle and with a narrow tail to the north. This may be the geomorphic expression of a large-scale sheared lens of volcanic rocks. If so, then it is analogous to the pervasive and anastomosing style of shearing common in outcrop, hand specimen, and thin section.

A pocket of cleaved Muddy Cove grey shale on the west shore of the pond upstream from Wallet Pond is lithologically identical to Silurian shales that enclose Ordovician blocks farther east and is the westernmost known occurrence of this type.

3.6 Burnt Arm to Cobbs Arm

The segment of New World Island Complex from Burnt Arm to Cobbs Arm is a classic melange (Map 1). Lithologic units of different ages are so mixed together that they can not be practically separated on maps with scales smaller than 1:50000; i.e. the area is truly a heterogeneous complex.

The western third of this segment is mainly Squid Cove Volcanics; the eastern third includes a thin slice of Squid Cove Volcanics more than two km long; and the middle third includes many smaller blocks and slices. Lithologic units are somewhat asymmetrically distributed across strike, and a southerly shale belt, defined by a larger percentage of Muddy Cove grey shale, extends eastward as far as Mussel Cove.

Squid Cove Volcanics are thrice-repeated from south to north in the western third of this segment. The southern imbrication is indicated by an isolated outcrop of Rodgers Cove Shale, with steeply northeast-plunging folds, just west of Long Pond Brook. The northern imbrication is indicated by an outcrop of Muddy Cove grey shale and schistose Cobbs Arm Limestone along the gravel road east of Burnt Arm; the volcanic block to the north and immediately east of Burnt Arm is abrubtly truncated farther to the east by a cross fault. To the south of the Cobbs Arm road, within the volcanic rocks, two cross faults bound a block that geomorphically resembles a graben.

In the middle third of the Burnt Arm-Cobbs Arm segment, including the southern shale belt, volcanic blocks range in size from blocks several meters across to slabs several hundred meters in length. Along the north shore of Long Pond, the contact between gray shale and the easternmost block of basalt is sharp; generally poor exposure, however, prohibits conclusions about the origin of the blocks. In the shale belt north of Upper Rogers Cove Pond, blocks of Muddy Cove sandstone may have been interbedded with the shale.

The southern contact of the New World Island Complex is difficult to pinpoint along this segment. It runs through Long Pond and the north edge of Gull Pond, where north- facing Silurian Milliners Arm conglomerates lie immediately south of Silurian Muddy Cove grey shale. East of Gull Pond, Silurian conglomerates are truncated eastward by a fault (the possibility that this contact marks an erosional channel filled with shale and olistoliths was considered; however, the largest known erosional channel, on Captain Jack's Island, is a low angle feature of a much smaller magnitude). These conglomerates are included in the Milliners Arm Formation, although a fault drawn by Williams (1957) extending from Upper Rogers Cove Pond to the west could be used to argue that the conglomerates are involved in the complex.

The northern contact of the New World Island Complex varies considerably between Burnt Arm and Cobbs Arm.

Just east of Long Pond Brook, Squid Cove Volcanics, Cobbs Arm Limestone, and Rodgers Cove Shale occur in apparently undisturbed stratigraphic order south of north-facing Crow Head Formation sandstone.

Faults bound the complex elsewhere. They include the cross fault east of the volcanic block near Burnt Arm, the adjoining fault along the Cobbs Arm road, the Mills Pond Fault, and the Little Cobbs Arm Fault.

The Mills Pond and Little Cobbs Arm Faults cut pre-existing structures and are grouped with other late faults. A boulder of intensely flattened polymictic conglomerate was found along the trace of Mills Pond Fault several hundred meters southeast of Mills Pond, indicating mylonitic deformation.

Isolated outcrops of Cobbs Arm Limestone occur along and north of Long Pond Brook. They pose a problem in their remoteness from the rest of the New World Island Complex. In a similar fashion, blocks of Squid Cove Volcanics are chaotically disposed along the northern margin of the complex east of Mills Pond.

3.7 Cobbs Arm

The New World Island Complex north of Rogers Cove Pond is composed mainly of Squid Cove Volcanics whereas to the south it is composed largely of Muddy Cove shale and various inclusions (Map 1).

On the peninsula between Rogers Cove and Cobbs Arm, Squid Cove Volcanics occur in three belts separated by Muddy Cove sandstone and shale. The volcanic belts are essentially unbroken, continuous slices. Harris (1966) attributed the outcrop pattern to normal faults, Kay to transcurrent faults (also in Harris 1966), and McKerrow and Cocks (1978) imply the slices are gravity slide sheets. The geometry is most consistent with the last interpretation, but fault contacts elsewhere in the complex suggest that the imbrication did not occur by a surficial process. Beds are locally more strongly overturned than in the Milliners Arm Formation to the south.

On the northeast tip of Cobbs Arm Peninsula, Muddy Cove clastics overlie Rodgers Cove Shale. The contact is folded,and a tight fold hinge of Muddy Cove clastics has been boudinaged such that a younger clast is enclosed by older matrix. (Fig. 18).

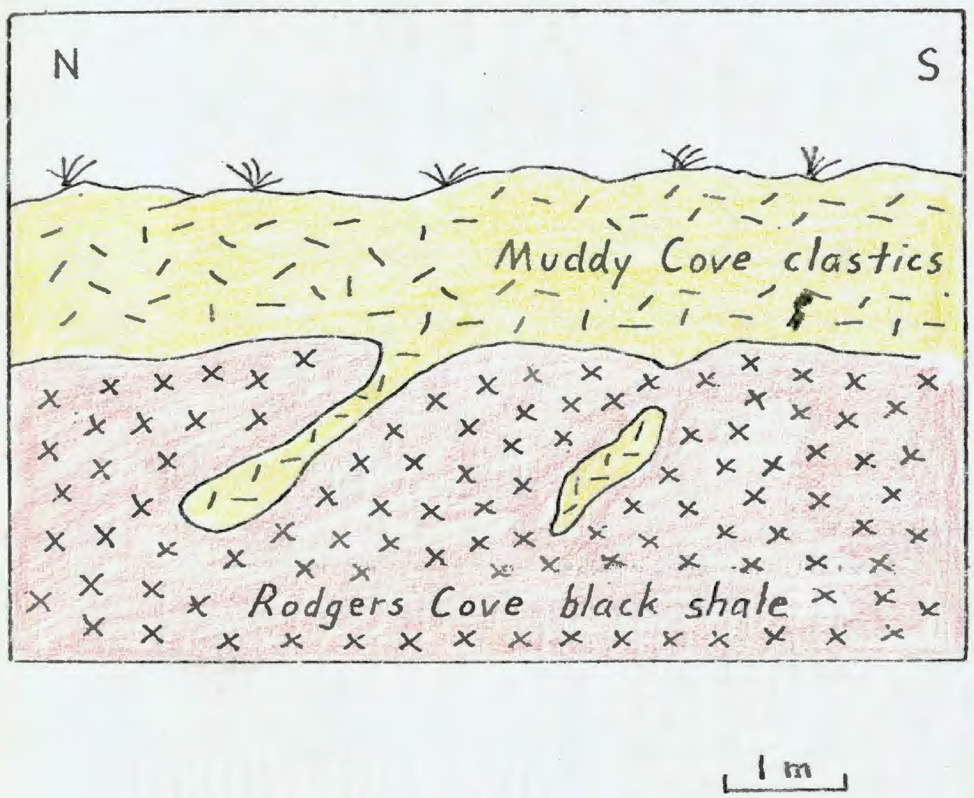

Figure 18: Deeply infolded contact between Muddy Cove clastics and Rodgers Cove black shale, southeast side of Cobbs Arm, directly opposite Quarry Cove Island. Note younger block in older matrix.

The southern contact of the New World Island Complex is chosen where north-facing Silurian conglomerates of the Milliners Arm Formation abut grey shales of the Muddy Cove Clastics. A large conspicuous hill southeast of Rogers Cove, composed of Silurian conglomerates, may be involved in the complex, but has more affinity with the Milliners Arm Formation adjacent to the south.

Along the north contact of the New World Island Complex, Cobbs Arm Limestone lies depositionally on Squid Cove Volcanics in the Cobbs Arm quarry. The actual contact between Rodgers Cove Shale, which occurs in a lone outcrop, and Crow Head Formation shale on the north side of Cobbs Arm is covered (cf. Williams 1963, p. 11: "Black graptolite-bearing beds (Rodgers Cove) are interlayered with grey silty beds, which grade into the typical interbedded greywacke and siltstone of map unit 8 (Crow Head)"). A stratigraphic contact is implied by the succession of progressively younger formations northward.

3.8 Rogers Cove to Mussel Cove

The segment from Rogers Cove to Mussel Cove is subdivided because of a wealth of detail. It basically consists of a southerly shale belt and a northerly melange belt (Map 2).

3.8.1 Rogers Cove proper

Silurian Muddy Cove grey shale of the southerly shale belt crops out along most of the southeast shoreline of Rogers Cove. Towards the east, volcanic rocks overlain by limestone and black shale are faulted against the Silurian shale (Map 2, location 1); the Ordovician section faces southeast and is the type locality of Rodgers Cove Shale. Along the fault is a narrow zone of intensely foliated shale. Shaly conglomeratic breccia occurs as a horizon in the shale several meters to the west. McKerrow and Cocks (1978) referred to the black shale as an "allochthonous mass" (olistolith), but they did not describe the faulted contact. The close proximity of sedimentary breccia and sheared rocks suggests a genetic link.

The section along the northeast end of the cove contains the best and most accessible exposures of melange in the New World Island Complex (Map 2, location 2). McKerrow and Cocks (1978) referred to it for the type section of their Big Muddy Cove olistostrome.

Two large outcrop-size slabs of Cobbs Arm Limestone are enclosed in Silurian Muddy Cove shale; boulder-size and smaller clasts of basalt and limestone are dispersed in the shale; and discrete horizons of breccia in the shale, which locally abut the larger slabs, also contain clasts (Plate 35; Fig. 19).

Brecciated Rodgers Cove Shale occurs on and mixed with limestone in the northern slab (Plate 35), and is the closest to being in stratigraphic contact with the Cobbs Arm Limestone anywhere in the complex.

The larger slab is fractured and intruded by Silurian shale (Plates 36, 37, and 38). Fragments of the limestone are engulfed as xenoliths. The shale can be traced inwards several meters and permeates the limestone in smaller veinlets (Plate 38). The shale differentiates to a more cherty composition inwards. Obviously, the limestone behaved in a drastically different brittle fashion compared to the mobile shale. The shale may have been wet. Differentiation of the shale suggests that the intrusion took place slowly, possibly at rates more compatible with tectonic deformation than with surficial slumping. A most plausible scenario is juxtaposition of lithified limestone with unlithified mud along a moving shear zone; limestone was plucked, fragmented, intruded, and finally incorporated in shale.

Locally, the margins of the limestone blocks are sheared and consist of rhombohedral-shaped limestone clasts

Plate 35: Large clasts of Cobbs Arm Limestone (light) in Muddy Cove shale (MC) of Silurian age, Rogers Cove. Large slab in right third of the photograph consists of Cobbs Arm Limestone (top), Rodgers Cove Shale (RC), and a zone where the two units are mixed together (middle).

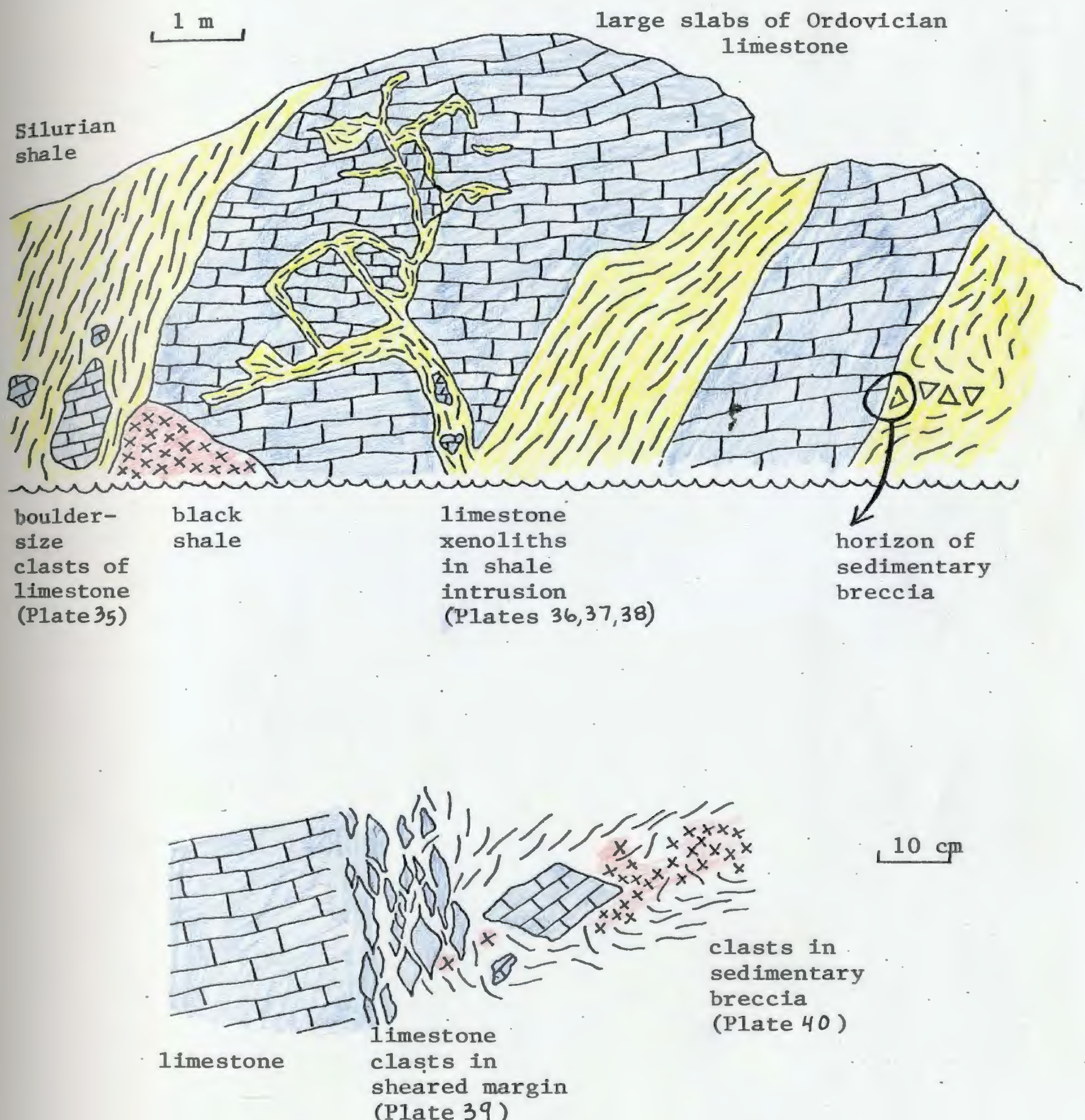

Figure 19 : Chaotic rocks, northeast end of Rogers Cove.
Not to scale.

Plate 36: Large fragments of Cobbs Arm Limestone (light) and dikes of Muddy Cove shale (dark) of Silurian age, Rogers Cove. Note smaller inclusions of limestone in dikes.

Plate 37: Angular xenoliths of Cobbs Arm Limestone in Muddy Cove shale of Silurian age, Rogers Cove.

Plate 38: Cobbs Arm Limestone permeated by dikelets and veins of Muddy Cove cherty shale of Silurian age, Rogers Cove.

interleaved with Silurian shale (Fig. 19; Plate 39). Aligned clasts of limestone that have delicate tips indicate hardrock shearing. Breccia horizons in the adjacent shale contain clasts supported by shaly matrix (Plate 40). Where the breccia and sheared margin abut, the contact is gradational between shale and sedimentary clasts in the breccia, and shale and fault clasts in the sheared margin.

The above arrangement could be interpreted as a fault scarp preserved in a shaly basin. Alternatively, the large slab may be transported as an olistolith, but the preservation of these delicate details suggests that it could not be far travelled. Again, the close physical association of coarse sedimentary deposits containing clasts derived from the local stratigraphic section and mylonitic rocks suggests syn-sedimentary faulting.

To the north, resistant sandstone forms the point of Rogers Cove (Map 2, location 3). Bedding is obliterated near the contact. At the contact with shale, the sandstone is brecciated (Plate 41). The contact was evidently a zone of movement, and the style suggests that materials were not completely lithified.

3.8.2 Rogers Cove to Joeys Cove

Plate 39: Sheared margin of Cobbs Arm Limestone slab surrounded by Muddy Cove shale, northeast shore of Rogers Cove. Note delicate tips and rhombohedral shape of limestone clasts controlled by shearing.

Plate 40: Diffuse horizon of sedimentary breccia near sheared margin of limestone slab (Plate 39), Rogers Cove. Black shale and limestone clasts are directly correlative with Rodgers Cove Shale and Cobbs Arm Limestone. Note foliation and crinoids in limestone clast suggesting that Ordovician rocks were inhomogeneously deformed in the Silurian as they are today.

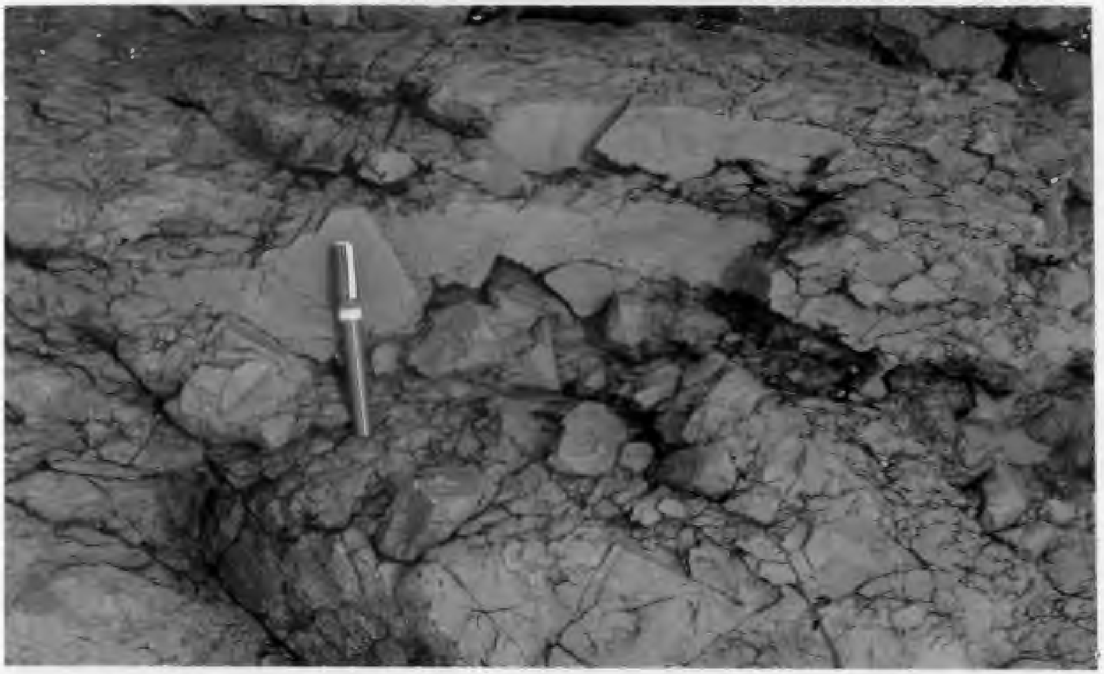

Plate 41: Brecciated sandstone near contact between units of Muddy Cove sandstone and shale, northeast shore of Rogers Cove.

Plate 42: Faulted syncline of thickly bedded Muddy Cove sandstone, Rogers Cove Entrance: an example of moderate structural complexity in the area.

Melange exposed at the northeast end of Rogers Cove (Map 2, location 2) extends northeastward to the peninsulas northwest of Joeys Cove (Map 2, locations 6 and 7). A prominent ridge with numerous limestone outcrops extends northeast from the two large slabs at Rogers Cove and bisects this domain. Northwest of the limestone ridge, Silurian shaly matrix is conspicuously absent, although units are chaotically distributed, sheared contacts are abundant, and less competent units are strongly deformed.

The sandstone section at the entrance to Rogers Cove faces and dips moderately to steeply south (Map 2, location 3). A faulted syncline of thick sandstone beds characterizes the locally complex structure (Plate 42).

To the east (Map 2, location 4), the contact between Rodgers Cove Shale and Muddy Cove Clastics is complexly folded. A thin isoclinal syncline of the clastics extends several meters into the black shale and is refolded. A fabric that varies from a spaced cleavage to concentrated shear zones is approximately axial planar to the folds. In the hinge area of an anticline, dissected by shear zones, several blocks of intact beds occur as autoclasts in a matrix of brecciated black shale (Plate 43). Where bedding is completely obliterated, the contact between black shale and green clastic rocks is intricately folded (Plate 44), and the mixture resembles the smeared green and black shaly

Plate 43: Rogers Cove Shale cut by brecciated shear zone, Rogers Cove Entrance. Note block of intact beds in lower left and truncated fold in upper right.

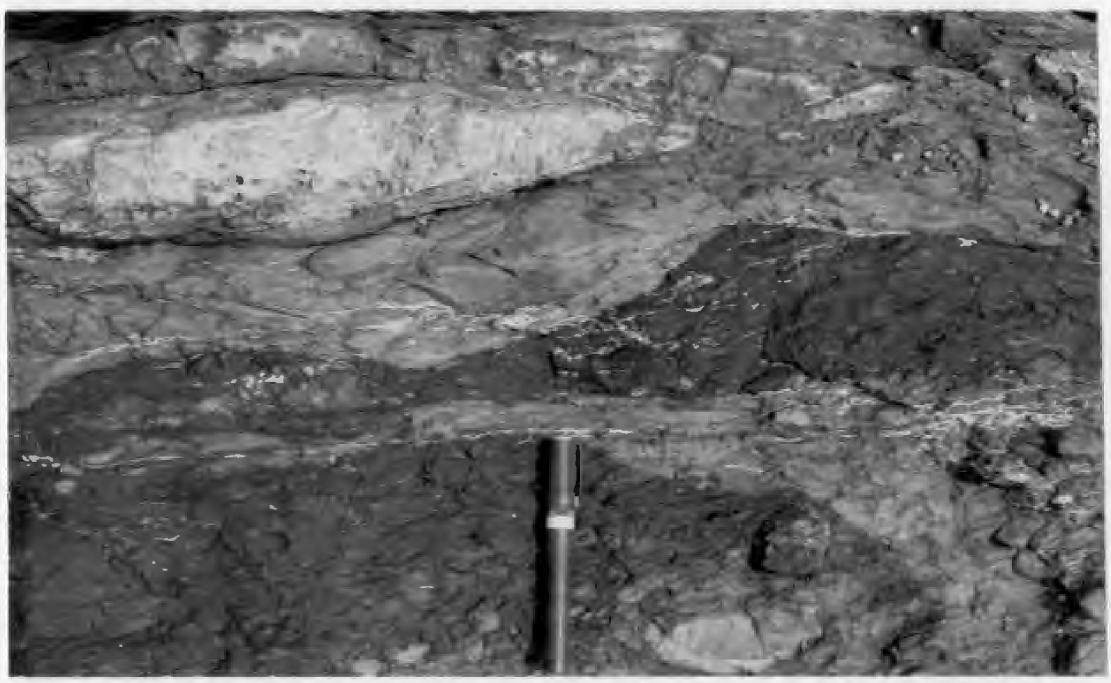

Plate 44: Flowage of Rodgers Cove black shale and Muddy Cove clastics, Rogers Cove Entrance. Slab in upper left is limestone.

matrix typical of other melanges (e.g. Dunnage Melange and melanges of the Humber Zone).

Farther to the east (Map 2, location 5), Cobbs Arm Limestone surrounds a small cove that was once a site of a quarry operation (Plate 45). The limestone shows spectacular inhomogeneous strain. On the point southeast of the cove, perfectly preserved crinoid columnals in well sorted grainstone are unstrained (Plate 15). On the point to the northeast, calcite mylonite with a prominent lamination occurs in a several cm wide zone separating two fault blocks (Plate 46). The northeast edge of the cove is a cross fault separating Cobbs Arm Limestone and Rodgers Cove Shale, which crops out at sea level. A small rhombohedral fault clast of Cobbs Arm Limestone is enclosed by Rodgers Cove Shale near the contact (Plate 47). At the quarry face in the bottom of the cove, the remaining limestone is bounded by green fault gouge containing numerous calcite veinlets and basalt clasts (Plate 48). Viewed from a distance (Plate 45), the matrix of fault gouge around the limestone slab appears as a large dike engulfing a megafragment of limestone.

Between the two peninsulas north of Joeys Cove (Map 2, locations 6 and 7), Muddy Cove sandstone and shale form matrix between a limestone block to the south and mixed limestone and basalt to the north. The northern contact is

Plate 45: Limestone quarry east of Rogers Cove Entrance. Block of Cobbs Arm Limestone on left side of photo contains a narrow zone of steeply dipping calcite mylonite (Plate 46) and is in fault contact with Rodgers Cove Shale (dark) to the right (Plate 47). The large fragment of Cobbs Arm Limestone forming the quarry face in the background is enclosed by fault gouge (Plate 48).

Plate 46: Narrow zone of laminated calcite mylonite in Cobbs Arm Limestone, east of Rogers Cove Entrance.

Plate 47: Rhombohedral clast of Cobbs Arm Limestone in sheared matrix of Rodgers Cove Shale near fault contact with the Cobbs Arm Limestone, east of Rogers Cove Entrance.

Plate 48: Clast of amygdaloidal basalt in matrix of fault gouge, quarry east of Rogers Cove Entrance. Note calcite vein.

well exposed (Plate 49; Map 2, location 6). Ordovician limestone and Silurian shale are tectonically interleaved along it (Plate 50). The tectonic nature of the contact is evident from the nature of the limestone, but is not evident from the appearance of the shale (i.e. hard rock and wet sediment deformation can not be easily distinguished in shale). The contact with the limestone block to the south is also presumably a fault. The change along strike from chaotic sediments(?) in Rogers Cove to tectonic contacts north of Joeys Cove demonstrates the extreme variability of tectonic styles in the New World Island Complex.

The southern limestone block (Map 2, location 7) is internally deformed in a hard rock fashion. Numerous calcite veins occur in conjugate sets (Plate 51) and also in parallel shear sets. Several fold pairs trend northwest and dip steeply (Plate 52), an anomalous orientation for folds in the area. The block-bounding fault is thought to be syn-sedimentary by correlation with nearby faults, and folds within the block must therefore be among the earliest structures in the area.

A lens of Rodgers Cove Shale occurs within the "matrix" of Muddy Cove shale and sandstone between the two peninsulas north of Joeys Cove (Map 2, locations 6 and 7). Along strike to the southwest, large clasts of Ordovician

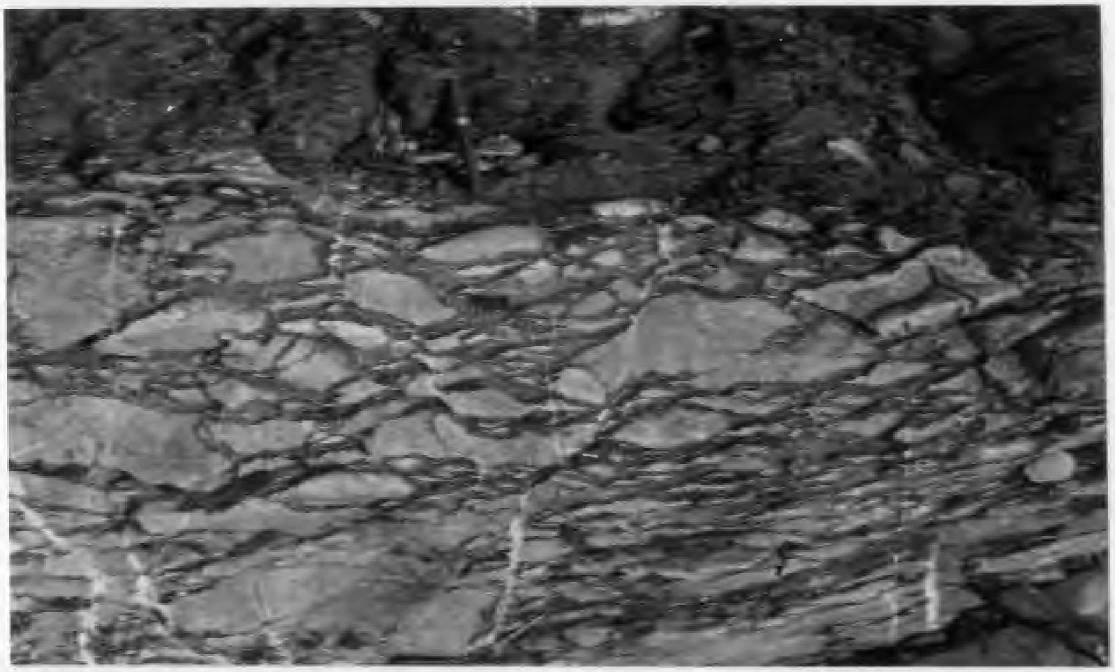

Plate 49: Interleaved Cobbs Arm Limestone and Muddy Cove shale, north of Joeys Cove. Tectonic nature of the contact is not particularly evident in the shale.

Plate 50: Tectonically interleaved Cobbs Arm Limestone and Muddy Cove shale, north of Joeys Cove (same location as Plate 49).

Plate 51: Fractured Cobbs Arm Limestone, north of Joeys Cove. Note two sets of calcite veins indicating extension.

Plate 52: Hard rock fold in fault block of Cobbs Arm Limestone, north side of Joeys Cove. The folds, with anomalous northwest trending orientations, pre-date the block-bounding fault.

basalt and limestone at the northwest end of Joeys Cove (Map 2, location 8) constitute a breccia horizon in Silurian Muddy Cove Clastics.

3.8.3 Joeys Cove to Mussel Cove

The section of Muddy Cove Clastics from Joeys Cove to Muddy Cove (see Arnott, 1983, Fig. 4, section 2, top part) includes:

1) a breccia horizon exposed in a cliff face at the bottom of Joeys Cove (containing a large (1+ m) boulder of sandstone; Map 2, location 9) and at the peninsula to the northeast (location 10);

2) overlying sandstone beds which face and dip south (location 11);

3) a thin breccia horizon (location 12); and

4) massive fossiliferous shale in which rare thin graded sandstone beds, although discontinuous, most commonly dip and face south (locations 13-16).

The contact between breccia along Joeys Cove and overlying sandstone beds is gradational (Map 2, location 10). The sandstone beds are dissected by numerous curvilinear faults at a low angle to bedding that have only small offsets. The sandstones contain Silurian fossils in basal lag deposits; unfossiliferous sandstones farther to the south (Map 2, location 11), which also dip and face south, are presumably stratigraphically higher.

The second breccia horizon occurs between the section of predominantly sandstone and predominantly shale (Map 2, location 12; Plate 24). It is composed of mainly black shale and chert fragments in a large proportion of shaly matrix. The significance of its position between two different units is uncertain. It probably represents a simple stratigraphic layer (debris flow deposit) that coincided with a change in style of sedimentation rather than a sedimentary shear zone over which the shale section rode.

Several of the structures in the section between Joeys Cove and Mussel Cove formed prior to cleavage, whereas most of the folds have an axial plane cleavage.

Pre-cleavage structures

Approximately ten meters west of the point at the head of Mussel Cove, a displaced sandstone bed indicates two faults, which are otherwise invisible (Plate 53; Map 2, location 15). The faults are parallel to cleavage. Two synforms occupy the intervening fault blocks. Facing of the sandstone bed is uncertain, although a faint grading suggests it might be overturned. Sand grains dispersed in

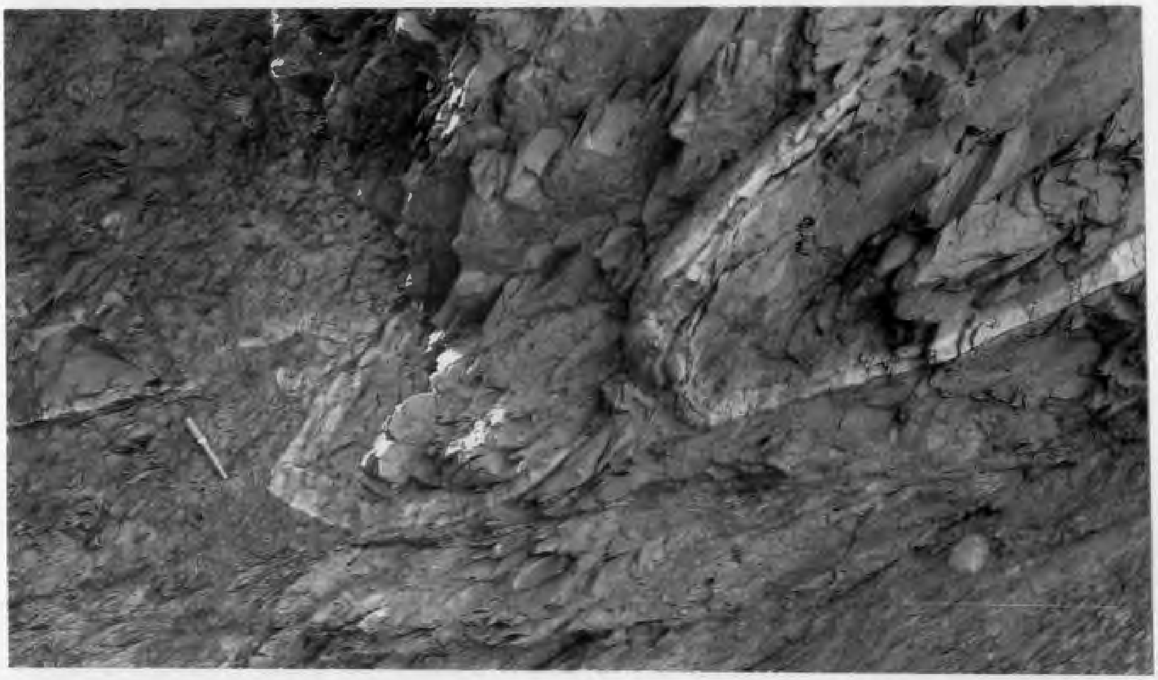

Plate 53: Sandstone bed in Muddy Cove shale folded into two synforms and broken by two faults, Mussel Cove. Style of the structures suggests that they developed in wet sediment. Displacement of the sandstone bed indicates transport to the southeast.

adjacent shale, a clump of sand grains that constitutes a ball structure, and dispersal of the bed along the fault all imply deformation by intergranular flow of unlithified sediment, thus dating the structure as pre-lithification. If the south dip of nearby beds is restored to horizontal, the faults are small scale thrusts to the southeast.

About a hundred meters to the southwest (Map 2, location 13), near an isolated upward-facing F2 syncline, an isoclinal southeast-facing syncline is also refolded into a synform (Plate 54). If the later synform is unfolded, and southeast dip of nearby beds is restored, the isocline faces south. Although asymmetry is not observed, the facing indicates transport to the southeast. If it is a slump fold, it indicates a southeast-facing paleoslope.

Climactic folds

On the shore of Joeys Cove (Map 2, location 10), two tight fold pairs have axial plane cleavage. Their asymmetry (S-folds looking northeast) indicates a larger anticline to the north.

Near the cove at the southwesternmost shale exposure (about halfway between Joeys Cove and Mussel Cove; Map 2, location 13), discontinuous northwest-facing beds are asymmetrically folded on a small scale. In relation to adjacent southeast-facing beds, the northwest-facing beds

Plate 54: Precleavage isoclinal syncline refolded into open climactic synform in Muddy Cove Clastics, east of Joeys Cove. Syncline faces down to the southeast and suggests early transport in that direction.

form the limb of a fold pair that has S-asymmetry (looking northeast), indicating again a larger anticline to the northwest. The small scale folds, of opposite Z-asymmetry, are parasitic on the inferred fold pair of intermediate scale. Cleavage may be axial planar to the small scale folds, suggesting that they and the intermediate scale fold pair are related to a larger F2 anticline to the northwest.

Folds farther east (Plate 55; Map 2, location 14) have northwest-facing limbs that are inferred to be short, indicating again, from the S-asymmetry (looking northeast), a larger anticline to the northwest.

A small fold on the west side of Mussel Cove (Map 2, location 16) also has S-asymmetry (looking northeast), but its generation is uncertain.

In summary, structures between Joeys Cove and Mussel Cove are mostly folds that have axial plane cleavage (Fig. 20). In the sandstone sections, and generally, cleavage dips more steeply than bedding. Most beds face southeast, and asymmetry of F2 folds indicates a larger anticline to the northwest. Facing of beds, cleavage, and small scale fold asymmetry are all reversed on the north side of Cobbs Arm, so that the inferred large anticline must be centered in Cobbs Arm. The same unit on either side of Cobbs Arm, i.e. melange in general although different rocks in

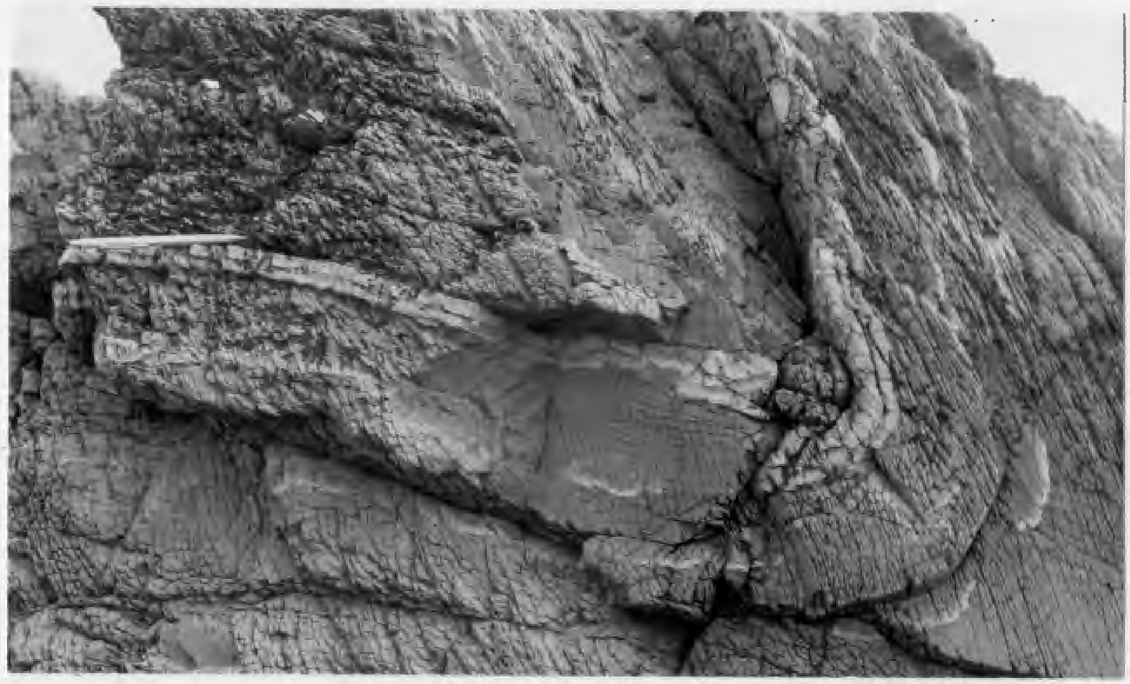

Plate 55: Climactic syncline facing up to the northwest in Muddy Cove Clastics, east of Joeys Cove. The axial plane cleavage dips southeast.

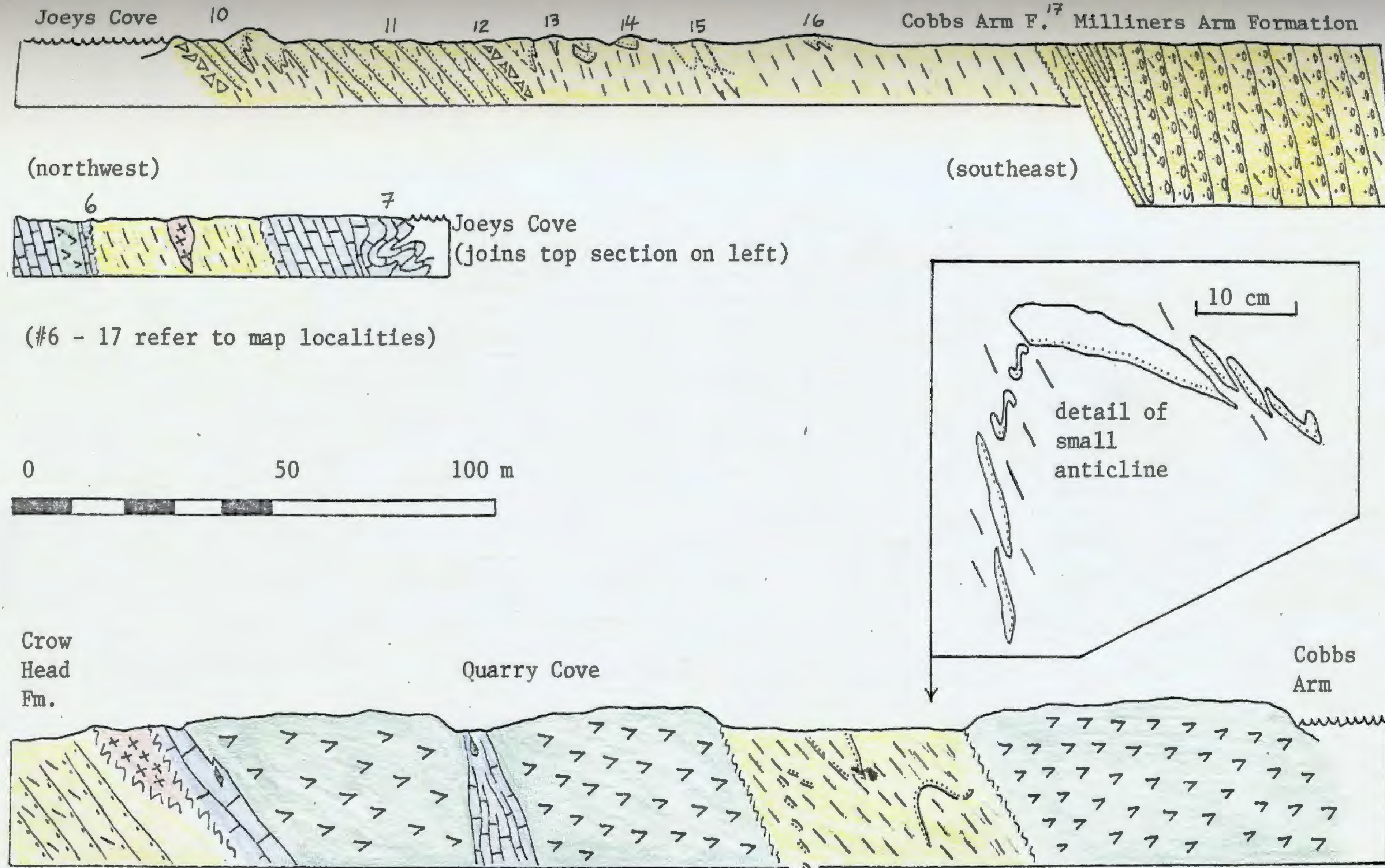

Figure 20: Cross sections of Mussel Cove and Joeys Cove area (top; southeast of Cobbs Arm) and Quarry Cove area (bottom; northwest of Cobbs Arm). Note syncline at top of Milliners Arm Formation and asymmetry of small-scale climactic (F2) folds indicating a large anticline centered in Cobbs Arm).

detail, also supports the contention of a large anticline. Furthermore, polymictic conglomerates in the middle of Cobbs Arm may represent a window through this anticline into the structurally lower Milliners Arm Formation.

In contrast, early structures have a different significance. If the later fold is undone, or, equally, the predominantly southeast dip of bedding is restored to horizontal, pre-cleavage structures indicate transport to the southeast. Fold generation, determined from overprinting and axial plane relationship of cleavage, is crucial to interpretation of fold asymmetry.

Disruption of bedding occurred within the section from Joeys Cove to Mussel Cove, but during which deformation is uncertain. Clumps of thin sandstone beds near the southeasternmost breccia represent a distinctive form of boudinage. Limestone pods, which contain fossils and are probably concretions, are randomly distributed in shale.

The Cobbs Arm Fault occupies a small gully between Silurian shale of the Muddy Cove Clastics to the north and south-dipping and facing sandstone beds at the top of the Milliners Arm Formation to the south (Map 2, location 17). An isoclinal syncline slightly farther to the south is inferred near the top of the Milliners Arm Formation, but the hinge is not exposed because of an intervening cross fault. The Cobbs Arm Fault, although not exposed, is necessarily inferred because lithic units are not completely repeated across the fold. Cleavage appears to be axial planar to the syncline. The syncline and the Cobbs Arm anticline form a major asymmetrical fold pair. South-facing beds at the top of the Milliners Arm Formation are sheared, more so than in the northwest-facing limb to the south, which represents a second form of F2 asymmetry.

The New World Island Complex is bounded to the east at Mussel Cove by a north-trending cross fault, the Mussel Cove Fault, that juxtaposes the complex against Milliners Arm Formation. A conglomerate bed has been partly faulted off to form a 1 meter block along the trace of the fault (Plate 56).

3.9 Quarry Cove and Reddicks Cove

A belt of Muddy Cove shale separates steeply dipping sections of Squid Cove Volcanics between Quarry Cove Island and Reddicks Cove Peninsula (Fig 21). The northern contact of the shale belt is a rubbly shear zone (Plate 57) overprinted by a clean planar fault (Plate 58) where it is exposed at the western end of Quarry Cove Island. Northeastwards, the bounding faults merge in an anastomosing fashion, but the single fault is not detected in the volcanic section south of Reddicks Cove.

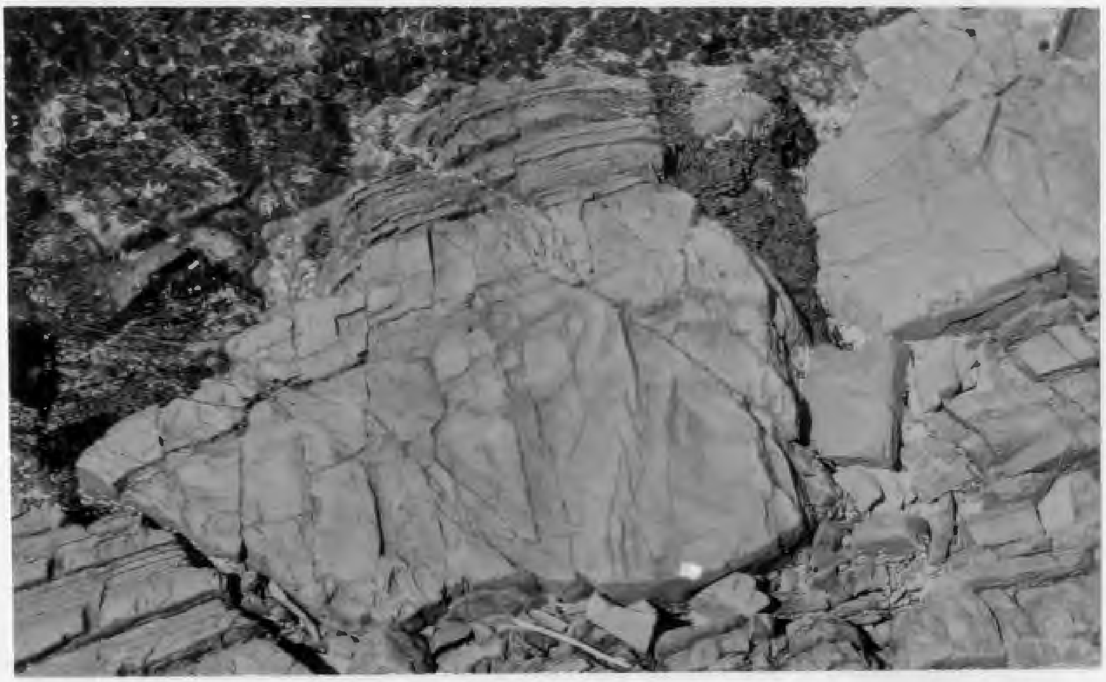

Plate 56: Block of Milliners Arm Formation sandstone along the Mussel Cove Fault, Mussel Cove.

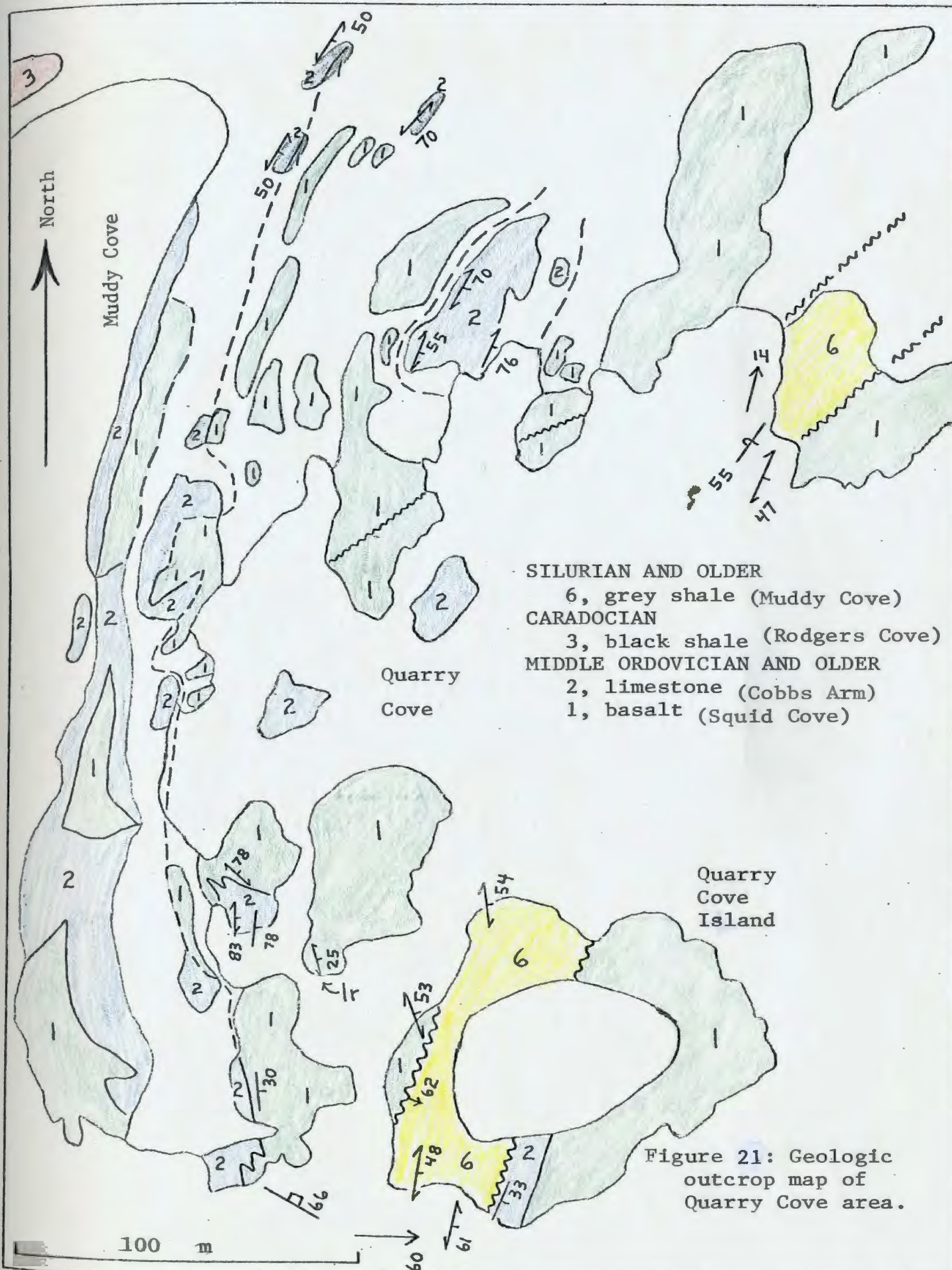

Figure 21: Geologic outcrop map of Quarry Cove area.

Plate 57: Rubbly shear zone between Squid Cove Volcanics and Muddy Cove shale, Quarry Cove Island.

Plate 58: Planar fault, Quarry Cove Island. Overprints shear zone of Plate 55.

In the matrix of Muddy Cove shale between the volcanic slices, fossils reported by Williams (1957) were not relocated; Harris (1966) included the shale in a Silurian unit. The unit locally contains streaks of darker shale similar to Rodgers Cove Shale.

Sandstone beds are discontinuous and boudinaged in the shale belt (Fig. 20). Rare graded beds generally face north. A train of boudins may be folded about cleavage (Plate 59); if so, boudinage is related to earlier shearing that involved juxtaposition of the volcanic blocks, and the folding was later. A syncline and an anticline slightly overturned to the northwest and a majority of beds that face northwest are parasitic structures on the northwest limb of the overturned Cobbs Arm F2 anticline (Fig. 20).

In the volcanic slice to the northwest, a string of limestone pods extends southwest toward and across Cobbs Arm. The limestone may be interbedded in the volcanics, or may represent a more complicated structure.

In one of the pods, the limestone is a calcite schist (Plate 60). At its contact with volcanic rocks, a lens of basalt several cm across is infolded into the calcite schist. Delicate wisps of basalt that are parallel to the schistosity indicate that the basalt clast is a tectonic

Plate 59: Train of sandstone boudins in shale, Muddy Cove Clastics, Quarry Cove Island. The train is possibly folded about the cleavage.

Plate 60: Clast of basalt in calcite schist incorporated during deformation, Quarry Cove.

Plate 61: Calcite schist and younger isotropic marble, Quarry Cove. Recrystallization obliterates tectonic foliation in schist, which obliterates primary features.

fragment, not a depositional feature. Nearby, coarsely crystalline marble is anisotropic (Plate 61). The schistosity has been overprinted, and this annealing has completely obliterated the tectonic fabric, which had previously obliterated primary features in the limestone.

Squid Cove Volcanics to the north are overlain by Cobbs Arm Limestone. On the hilltop near the bottom of Muddy Cove, an angular basalt clast in intensely stylolitic limestone is believed to have been incorporated during tectonic flow (Plate 62). The stylolites indicate that pressure solution was important as a deformation mechanism in addition to dislocation creep characteristic of the calcite schists.

Rodgers Cove Shale occurs still farther to the northwest, indicating little disturbance of the stratigraphy. The Muddy Cove and Reddicks Cove Faults also occur at this northern contact of the New World Island Complex. Rocks along the southeast shore of Muddy Cove are sheared. The Rodgers Cove Shale seems to have localized faults.

At the bottom of Reddicks Cove, in the southwest corner, the northernmost Cobbs Arm Limestone is mylonitic (Fig. 22). Rodgers Cove Shale is exposed in sea level outcrops to the north. On the north side of the cove, drag

Plate 62: Angular chunk of Squid Cove basalt in stylolitic Cobbs Arm Limestone incorporated during deformation, Muddy Cove. Units are inverted.

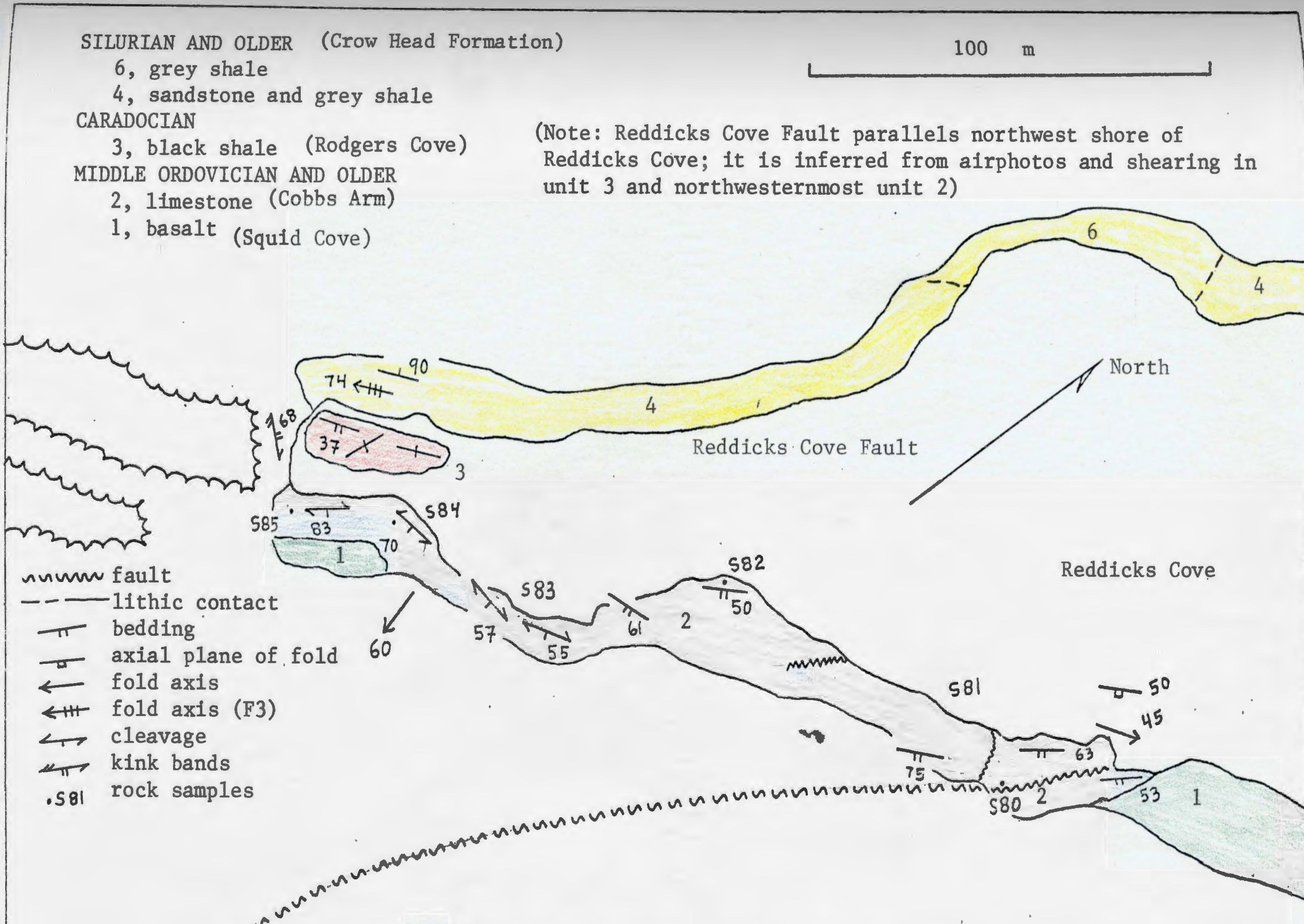

Figure 22: Geologic outcrop map of Reddicks Cove.

folds that indicate sinistral movement along the Reddicks Cove Fault seem to have affected cleavage in Crow Head shale.

Eastwards, near the tip of Reddicks Cove Peninsula, red shale occurs plastered onto the volcanic cliffs. It is sheared, and Harris (1966) drew a fault along this shoreline towards Boyds Island.

3.10 Boyds Island

Boyds Island consists of four large blocks of Squid Cove Volcanics separated by shaly matrix that contains a variety of inclusions (Fig. 23). Fault contacts between the volcanic blocks and shaly matrix are suggested by foliated limestone at the margin of the westernmost volcanic block at the southwest end of the island. The shape of a basalt sliver also suggests tectonic incorporation into shaly matrix (Plate 63). The volcanic blocks are therefore interpreted as competent inclusions in an anastomosing network of shaly shear zones.

Most of the matrix is grey shale assigned to the Muddy Cove Clastics. It includes streaks of green shale, which has flowed together with the grey shale. Rare discontinuous sandstone beds parallel to cleavage indicate

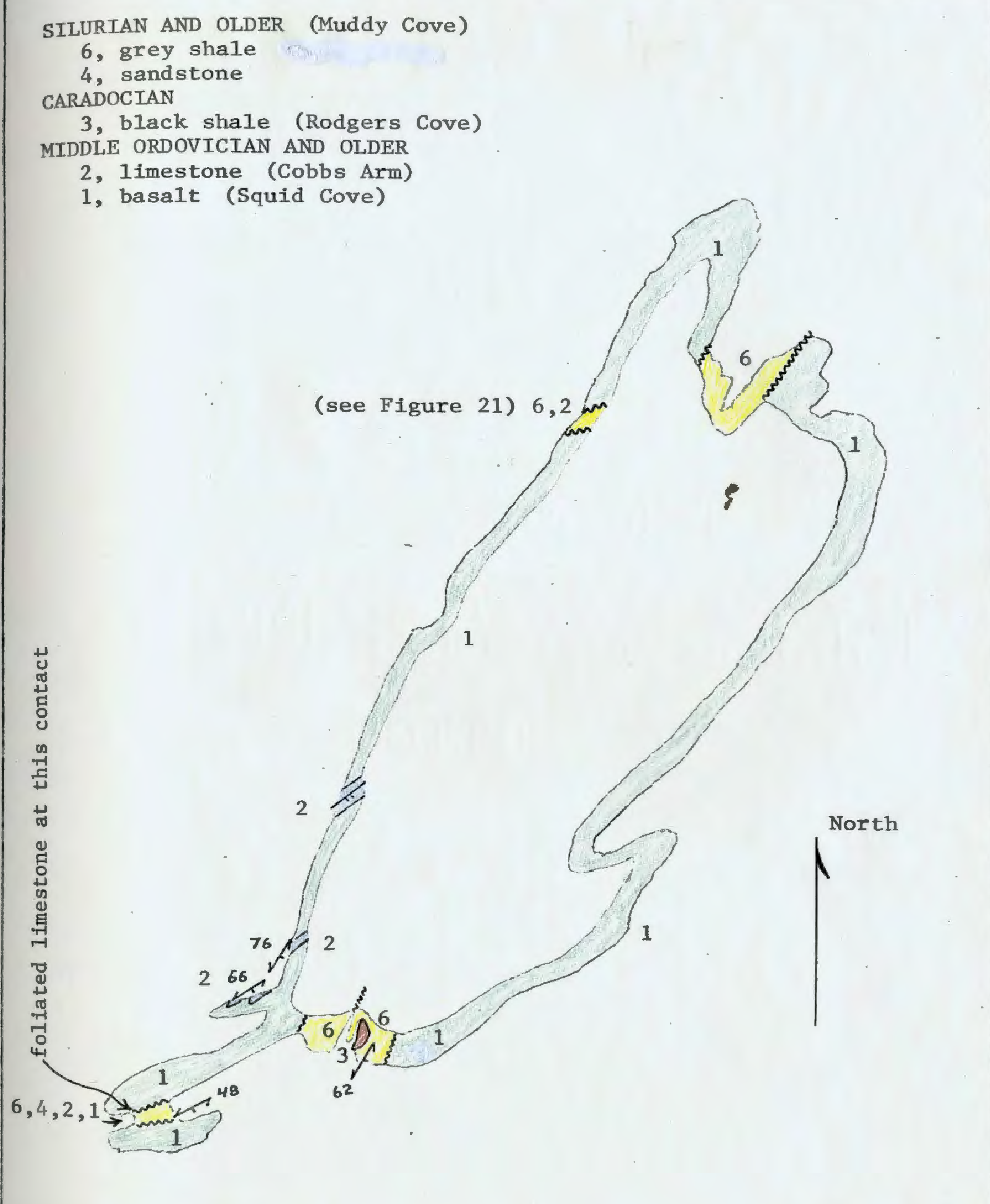

Figure 23 : Geologic outcrop map of Boyds Island.

Plate 63: Sliver of basalt in Muddy Cove shale, Boyds Island. Note flowage of green and grey shale and intense cleavage development.

Plate 64: Round mass of basalt in tuffaceous matrix, Boyds Island. It may be an undeformed pillow.

that bedding is transposed. Locally, at the southwest end of the island, where green tuffaceous matrix contains a relatively undeformed basalt pillow (Plate 64), some of the matrix may belong to Squid Cove Volcanics. A large mass of Rodgers Cove black shale to the northwest is an inclusion in grey shale (Plate 65); it has a sharp, locally rectilinear contact with the grey shale, and the two are probably in fault contact.

On the northwest shore of the island, a shaly shear zone contains a slab of asymmetrically deformed limestone (Plate 66; Fig. 24). The ends of the limestone slab were faulted or folded, and the simplest interpretation of this geometry is that the southern volcanic block was displaced upward. Alternatively, if the limestone slab was boudinaged during early faulting and was later folded, the Z-asymmetry (looking northeast) indicates position on the north-facing limb of a large anticline to the south.

3.11 Duck Island

The bulk of Duck Island is Squid Cove Volcanics. At its east end, a block of Squid Cove Volcanics over a hundred meters long is separated from volcanics to the north by a narrow belt of sediments, namely Rodgers Cove Shale overlain conformably by Muddy Cove shale and

Plate 65: Mass of Rodgers Cove black shale enclosed by Muddy Cove gray shale of post-Caradocian age, Boyds Island. Bedding is obliterated in both units. Note sharp contact on right and its rectilinear extension towards the upper left of the photo.

Plate 66: Slab of limestone in shaly shear zone between volcanic blocks, Boyds Island (see Figure 24 for further description).

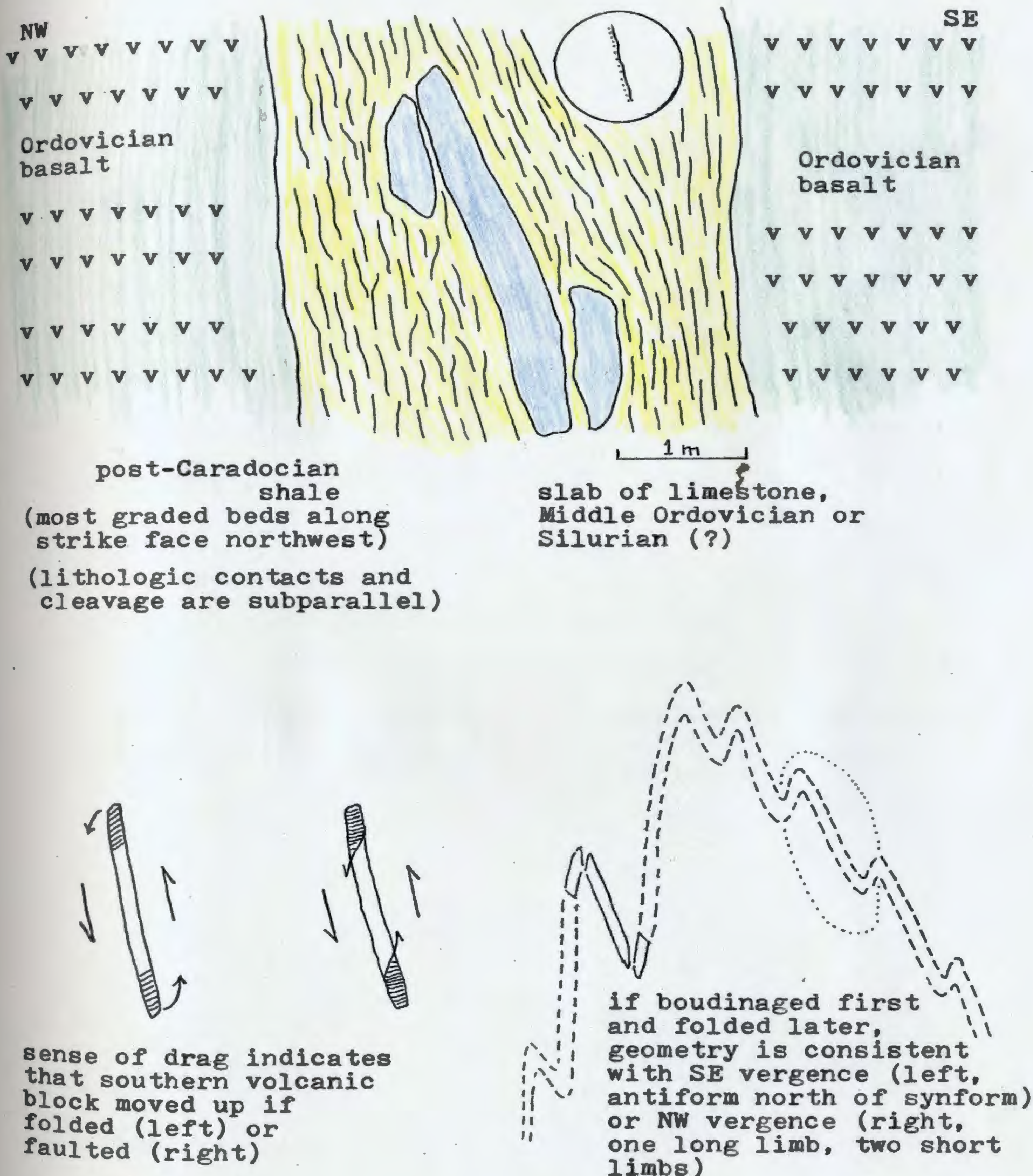

Figure 24 : Shaly shear zone, Boyds Island, and interpretations of relative displacement.

sandstone (Fig. 25).

The Rodgers Cove Shale and Muddy Cove Clastics are folded into a relatively simple upright anticline with parasitic folds on the limbs, defined by the formational contact (Plate 67). Cleavage is axial planar to the fold. The formational contact is truncated along strike at the volcanic rocks, where red shaly shear zones several cm wide contain dispersed inclusions of basalt (Plate 68). The inclusions range in size from several tens of cm to microscopic particles. The intense foliation and chlorite associated with incorporation of the volcanic particles indicate that the shale is mylonitic. The volcanic block is therefore fault bounded and is not an olistolith. Both faults may be the same one if folded about the upright anticline, in which case it is a spectacular example of a folded thrust; the volcanic block would then be a klippe. The entire structure is truncated along strike to the northeast by a cross fault.

Folds on the northwest limb of the anticline vary from open (Plate 69) to isoclinal (Plate 67), such that some younger Muddy Cove Clastics is deeply folded into the Rodgers Cove Shale. Minor offset along a cross fault has partially isolated an anticlinal hinge of Rodgers Cove Shale within Muddy Cove sandstone. At the hinge of the main anticline, a sandstone bed is boudinaged, and boudins

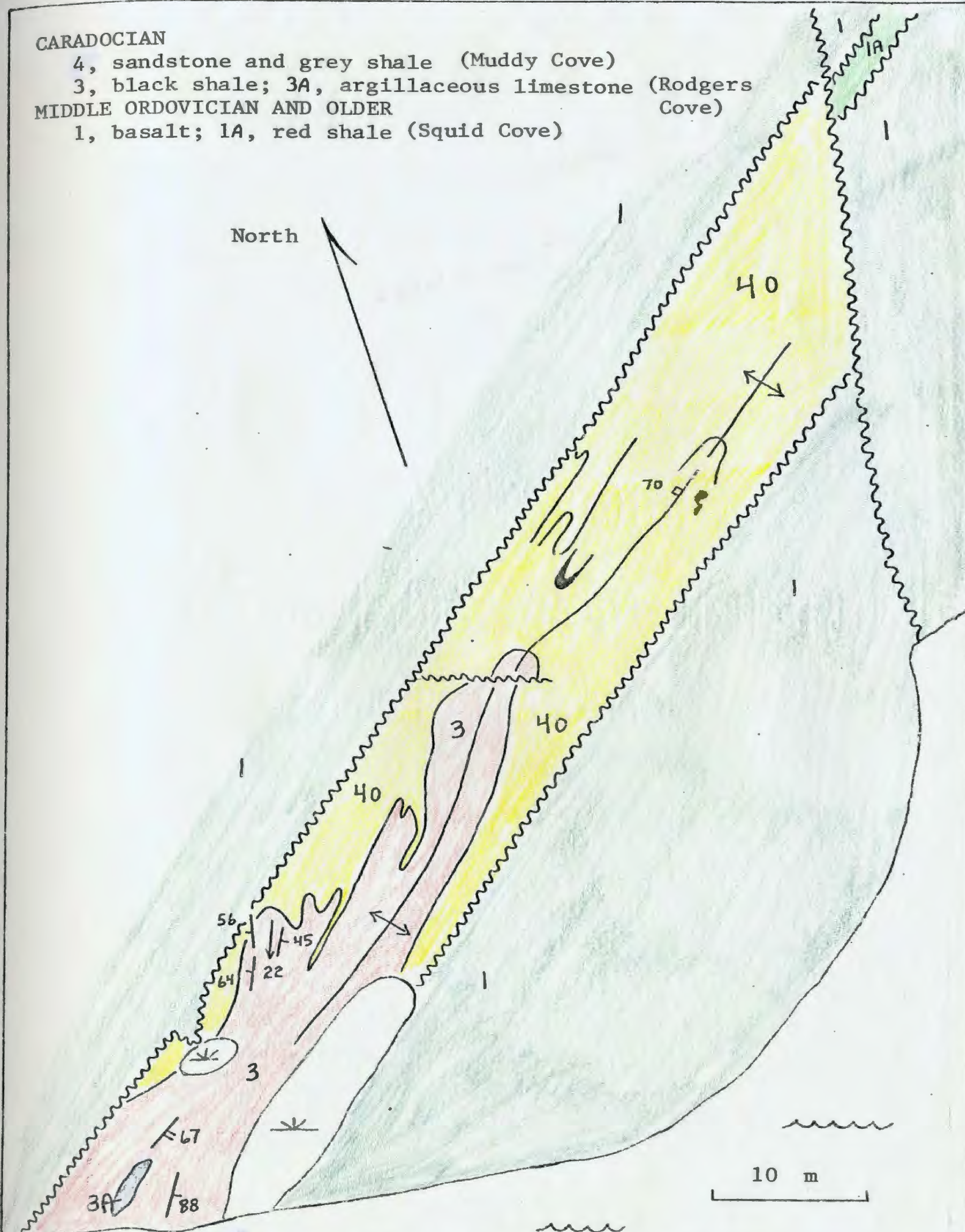

Figure 25 : Geologic map of Duck Island, east end.

Plate 67: Folded conformable contact between Rodgers Cove Shale and Muddy Cove sandstone, Duck Island. Note tight syncline on left.

Plate 68: Shear zone of basalt inclusions in intensely foliated red shaly matrix, Duck Island. Separates Squid Cove Volcanics from younger sediments.

Plate 69: Relatively open anticline in Rodgers Cove Shale, Duck Island.

Plate 70: Tight hinge of largest anticline on Duck Island, in Muddy Cove Clastics. Note fragments of sandstone bed dispersed in shale in hinge area.

apparently formed at the same time as the F2 fold (Plate 70). Within the Rodgers Cove Shale, an argillaceous limestone slab represents a detached bed.

Squid Cove Volcanics to the north contain several horizons of red shale. The red shale everywhere has a strong foliation and is sheared. If each layer is not a different bed but the same one repeated, then the volcanics are intensely imbricated.

3.12 Summary of structural relationships within the New World Island Complex

In the two concluding sections of this chapter, salient features of the New World Island Complex are summarized and their significance is discussed.

The New World Island Complex varies from a belt of imbricated volcanic slices (mainly west of Burnt Arm) to a melange of volcanic blocks in younger sediments (mainly the shale-block belt east of Burnt Arm, but also west of Burnt Arm along the southern and northern? contacts of the complex). Locally, along the north flank of the New World Island Complex, volcanic rocks are continuous with the overlying Crow Head Formation (see following section, 3.13 on external contact relationships).

Imbricated slices

Imbricated slices are recognized by stratigraphic repetitions in continuously northwest-facing rocks (e.g., Virgin Arm, Tilt Cove, and Cobbs Arm Peninsula). Red shale occurs at the base of volcanic slices (Duck Island, Tilt Cove) and may have acted as a detachment surface or decollement. Caradocian shale is also a significant incompetent horizon which localized movement. Bedding more overturned within the New World Island Complex than within the Milliners Arm Formation to the southeast suggests that northwesterly slices were displaced relatively upward.

Contacts between slices are movement surfaces of tectonic origin, indicated by recrystallization that is generally of a mylonitic nature (e.g., calcite mylonite along the Twillingate Highway, cherty mylonite along the Cobbs Arm Fault in Tilt Cove, volcaniclastic? mylonite along Virgin Arm, and red shale mylonite on Duck Island). Certain "soft" contacts between shale and more competent rock are also demonstrably of tectonic origin (e.g., Silurian shale tectonically interleaved with Ordovician limestone north of Joeys Cove). Many shear zones contain inclusions that were incorporated and transported by shearing (e.g. on Duck Island, foliated red shale contains a poorly sorted admixture of basalt, which itself is sheared along surfaces of chlorite).

Fault contacts are generally steeply dipping and inclined at a small angle to predominantly steeply dipping beds in the area. This relationship indicates they cannot be syn-sedimentary normal faults. With a stratigraphic separation of more than 1 or 2 km, the dip-slip displacement must be considerable. A large dip-slip displacement is unlikely along a steeply-dipping fault because of 1) the unrealistic amount of uplift required (tens of kilometers) and 2) uniform metamorphic grade in adjacent fault blocks; a more likely explanation is large displacement along a gently-dipping fault that was later steepened. Locally the faults dip steeply southeast, but less steeply than bedding in the Milliners Arm Formation (e.g., Cobbs Arm Fault, Tilt Cove) suggesting they cut up the Milliners Arm Formation from the northwest.

Sedimentary slices between competent volcanic slices are invariably deformed, with bedding partially obliterated to boudinaged and also smeared to sheared (e.g., Virgin Arm, north of Fairbanks East). Bounding faults locally merge (Quarry Cove-Reddicks Cove Peninsula) such that sedimentary slices pinch out laterally, and an anastomosing pattern is formed. Shaly sedimentary slices are particularly deformed and display intense cleavage development (e.g., Boyds Island); they contain various inclusions, such as boudinaged sandstone interbeds. Incompetent sedimentary slices can therefore be regarded as shear zones between competent volcanic slices. A continuous gradation exists from these to the sedimentary matrix between volcanic blocks in melange.

<u>Melange</u>

Melange does not consist simply of blocks in <u>Silurian shale</u> (Fig. 26), e.g. blocks of Cobbs Arm Limestone occur

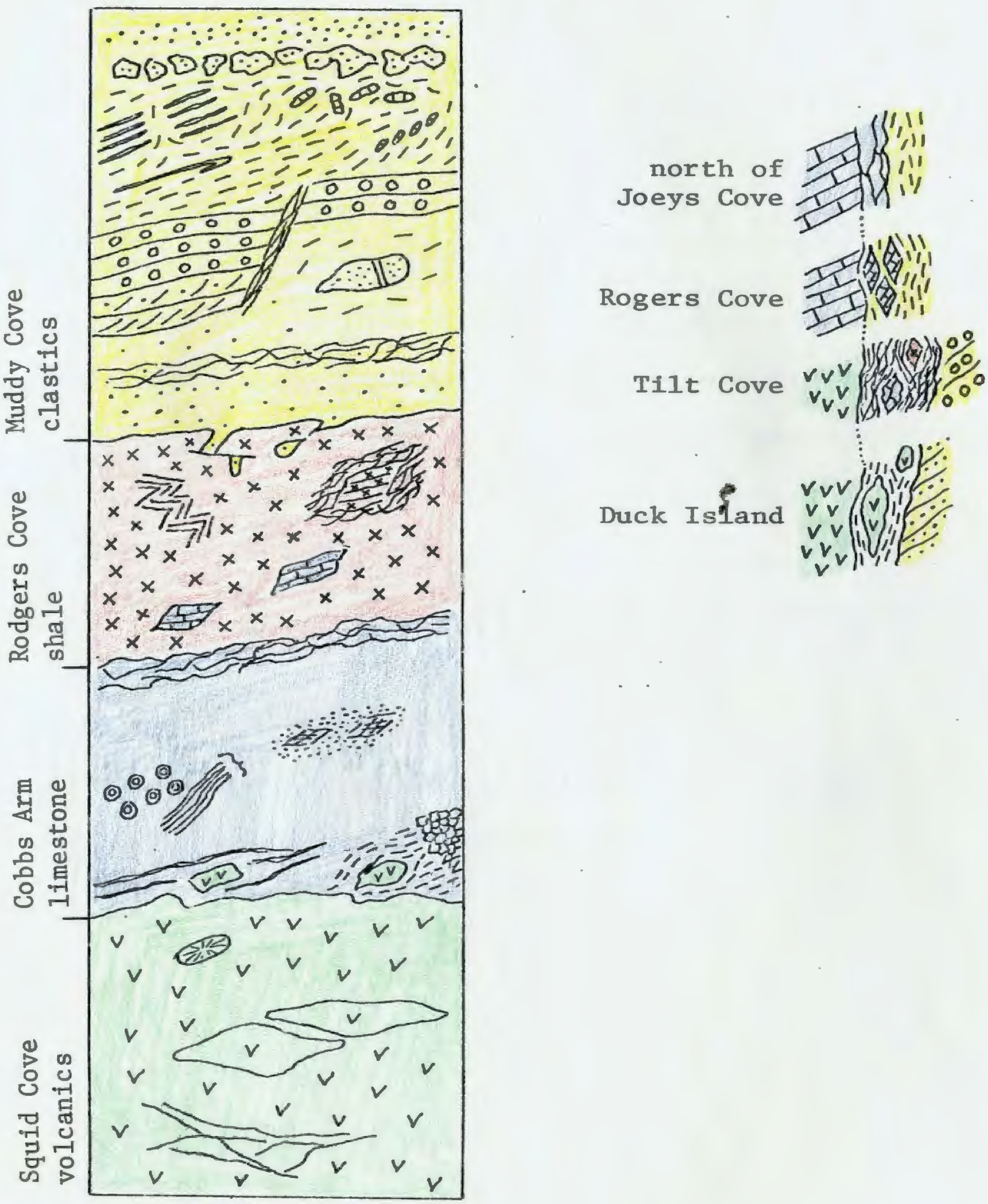

Figure 26 : Clastic fabric, variable strain, and mixtures in relation to stratigraphy.

in shaly matrix of Caradocian age (near Rogers Cove, Map 2, location 5) and volcanic clasts occur in a matrix of ductilely deformed limestone. Also, younger blocks occur in older matrix, e.g. a fold hinge of Muddy Cove Clastics was boudinaged and enveloped by older Caradocian matrix (peninsula southeast of Cobbs Arm).

The melange is polygenetic. There are at least three stratigraphically distinct horizons of sedimentary breccia, two between Joeys Cove and Mussel Cove and also in Rogers Cove. The sedimentary breccias are the only proven chaotic sediments, and many other chaotic elements are definitely of tectonic origin. The most problematic elements are boulders and larger fragments of limestone dispersed in shale because they could be either 1) olistoliths or 2) fragments dispersed in unlithified mud along a syn-sedimentary fault or shear zone. The second explanation is preferred because intrusion of Silurian shale into a fragmented slab of limestone appears to have been slow enough to allow compositional differentiation inward along dikes (shale becomes more cherty); the limestone behaved in a brittle fashion and was lithified, whereas the extreme mobility of the shale suggests it was highly ductile mud at the time of intrusion. This slow juxtaposition of rock with sediment is best explained by syn-sedimentary shearing.

Again, neither a block-matrix relationship nor "soft" contacts are diagnostic of a sedimentary deposit. Sandstone boudins enclosed in shale and in sharp contact with it (Duck Island) formed relatively late in the hinge of an anticline with axial plane cleavage. The shapes of a 1 m volcanic sliver in shale (Boyds Island) and 10 cm limestone lozenge within a shale intrusion (Rogers Cove, Plate 36, same intrusion as mentioned in last paragraph) suggests the inclusions were formed and incorporated in the shale by shearing. Their shape is probably not due to later shearing because the ductile matrix should protect the competent inclusions from further distortion, i.e. the inclusions would behave as rigid bodies.

Complex as a fault zone

Widespread shearing within the New World Island Complex, not only between imbricated slices but also laterally within melange, indicates that the complex is a fault zone (or shear zone). Nowhere can it be demonstrated that shearing is confined to olistoliths; rather, a block that has been postulated to be an olistolith (McKerrow and Cocks 1978) has a locally sheared margin.

Timing of faults

A variety of features and relationships within the New World Island Complex suggest that movement along faults commenced prior to the end of sedimentation (i.e., they are syn-sedimentary); faulting may also have continued through and perhaps after climactic (F2) folding.

Syn-sedimentary faulting

Chaotic sediments, pre-cleavage structures, and pre-lithification structures occur at the top of the stratigraphic section. They are spatially associated with mylonites, i.e., all four are localized within the New World Island Complex, which suggests syn-sedimentary faulting. Examples include:

1) a fold formed in wet sediment along Virgin Arm;

2) actual thrusts that displaced wet sediment near Mussel Cove;

3) a pre-cleavage fold between Muddy Cove and Joeys Cove;

4) lithified limestone juxtaposed slowly with wet mud (see discussion of limestone intruded by shale under Melange);

5) sedimentary breccia containing an inhomogeneously deformed clast of limestone that correlates with the local stratigraphic section in another fault block; and

6) occurrence of sedimentary breccia very close to sheared shale that bounds a block of Ordovician rocks in the bottom of Rogers Cove; nearby, sedimentary breccia abuts and

actually is gradational with the sheared margin of a limestone slab, a relationship that can be interpreted as a fault scarp preserved in the geologic record.

Folded faults

The relationship between faults and subparallel bedding, which was previously discussed under Imbricated slices, suggests a large amount of displacement along gently dipping faults before they were steepened by folding. A large amount of displacement is also suggested by major facies differences between slices compared to minor lateral variation within slices (see discussion at end of next chapter).

Faults and melange appear to be folded by climactic (F2) folds in three places (Fig. 27):

1) on Duck Island, where a red shaly shear zone and volcanic blocks are repeated on either side of an upright anticline with axial plane cleavage;

2) along the Twillingate Highway, where calcite mylonite is folded with an asymmetry like that of other F2 folds in the area; and

3) across Cobbs Arm, where melange occurs on either side and conglomerate (Milliners Arm Formation?) occurs in the middle, possibly a window through the melange; an antiform is inferred from opposite facing of beds, bedding-cleavage

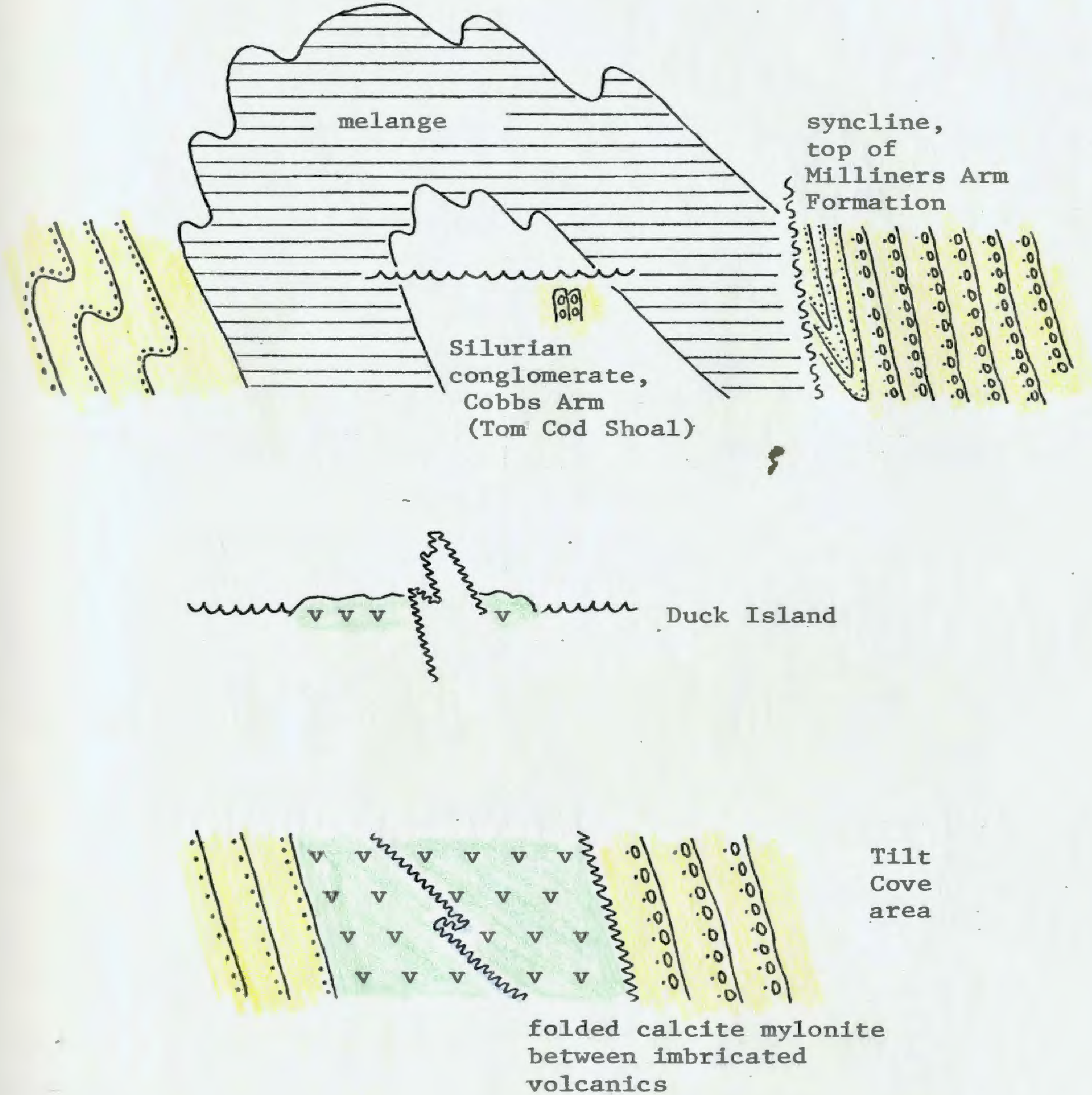

Figure 27 : Steeply dipping faults and fault zones (melange) interpreted as folded thrusts.

relationship, and small scale fold asymmetry, including the asymmetries of a folded boudin train (Quarry Cove Island) and of a dismembered limestone slab (Boyds Island), on either side of Cobbs Arm.

Faulted folds

An isolated east-facing climactic (F2) fold limb of Muddy Cove sandstones in Tilt Cove suggests that faulting continued after climactic folding. More evidence suggesting syn and post-F2 faulting is presented and discussed in the following chapter on nearby formations.

Polarity of thrusts

The facing of a pre-cleavage fold and thrusts that displace wet sediments near Mussel Cove indicate that earliest transport was towards the southeast. Southeast-directed thrusting is also suggested by the relationship between faults and bedding and sense of imbrication, which were both discussed previously in the section on Imbricated slices. Basin polarity considerations discussed at the end of the next chapter also suggest that higher slices initially lay towards the northwest. Structures in adjacent formations also bear on polarity of the thrusts, and are described and discussed in the next chapter.

Late cross faults and "volcanic" cross faults

Late cross faults, such as the Burnt Arm Fault, displace the New World Island Complex, and clearly post-date its formation.

The age of cross faults confined to the New World Island Complex and possibly to the Squid Cove Volcanics is uncertain: they are either pre-Caradocian structures within the volcanic rocks or faults that are conjugate with one of the other two sets of faults.

3.13 Summary of external contacts

No stratigraphic contacts are exposed along the northern flank of the New World Island Complex, i.e. Rodgers Cove Shale and Crow Head Formation can not be demonstrated to be interbedded. At the only exposed contact in Squid Cove, shales of the two formations are smeared together. Elsewhere, the contact is the site of minor faults, such as Reddicks Cove, Little Cobbs Arm, Mills Pond, and an inferred fault between Wallet Pond and Burnt Cove. The order of generally northwest-facing Squid Cove Volcanics, Cobbs Arm Limestone, and Rodgers Cove Shale followed northward by Crow Head Formation, which is preserved at six places (Squid Cove, Burnt Cove, east of Burnt Arm, Cobbs Arm, Muddy Cove, and Reddicks Cove), strongly suggests stratigraphic order and an initially conformable section, now structurally modified.

The Cobbs Arm Fault bounds the New World Island Complex on the south, where it locally places north-facing Ordovician Squid Cove Volcanics against north-facing Silurian conglomerate of the Milliners Arm Formation. Elsewhere, the contact is a more diffuse zone of chaotic rocks or, at Mussel Cove, a fault that separates south-facing Silurian Muddy Cove shale from south-facing Silurian Milliners Arm sandstone.

CHAPTER IV

NEARBY FORMATIONS

Several formations that occur near the New World Island Complex (Map 1) and that bear on its origin and setting are described briefly in the following chapter. The Clarkes Cove Volcanics occurs along with the Rodgers Cove Shale (which was previously described) in a belt that extends from Little Byrne Cove to Clarkes Cove. The Milliners Arm, Crow Head, and Indian Cove Formations, correlatives of the Muddy Cove Clastics, occur, respectively, southeast of the New World Island Complex, northwest of the New World Island Complex, and northwest of the Clarkes Cove Volcanics. The Byrne Cove Melange is a narrow, discontinuous belt of chaotic rocks along the contact between the Crow Head Formation and Clarkes Cove Volcanics.

4.1 Clarkes Cove Volcanics

The name Clarkes Cove Volcanics is proposed for volcanic and related rocks that occur in a belt between Little Byrne Cove and Clarkes Cove (Map 1). No more than about 100 metres of section is present at any one place. The Clarkes Cove Volcanics were previously included in map units 4 and 11 of Williams (1963). Kay (1976) assigned them to the Summerford Formation. McKerrow and Cocks

(1978) included them as olistoliths in their Big Muddy Cove Group.

Lithology

The Clarkes Cove Volcanics consist mainly of basalts, minor pyroclastic rocks, and interstitial limestone. Basalt is strongly sheared near the Clarkes Cove Fault along the Cobbs Arm road.

Structure and contacts

Clarkes Cove Volcanics crop out discontinuously in a steeply dipping belt between Little Byrne Cove and Clarkes Cove (Map 1).

Slivers of the Clarkes Cove Volcanics are locally incorporated within shales of the Crow Head Formation at Little Byrne Cove and at Clarkes Cove, which Arnott (1983) referred to as the Byrne Cove Melange. At Clarkes Cove, limestone of the Clarkes Cove Volcanics is strongly foliated at the contact with Crow Head shales.

The Clarkes Cove Volcanics is overlain by Rodgers Cove Shale at Little Byrne Cove and is unconformably overlain by the Indian Cove Formation in Clarkes Cove, a relationship described in more detail in the section on the Indian Cove

Formation.

Age and correlation

Fossils have not been collected from the Clarkes Cove Volcanics. However, with the exception of Williams (1963), who included the volcanic rocks at Clarkes Cove in his map unit 11 of the Silurian Botwood Group, the Clarkes Cove Volcanics have been unanimously correlated with the Squid Cove Volcanics of pre-Caradocian age.

Significance

The Clarkes Cove Volcanics are significant in that they are direct correlatives of the Squid Cove Volcanics. Whereas the Squid Cove Volcanics are intimately involved in a Silurian melange, the Clarkes Cove Volcanics have a clear stratigraphic relationship with their overlying unit.

4.2 Milliners Arm Formation

Name, definition, distribution, and thickness

The name Milliners Arm Formation was applied by McKerrow and Cocks (1978) to shale, sandstone, and conglomerate on eastern New World Island that occurs to the southeast of the New World Island Complex. It is well exposed in the type section from Dildo Run to Cobbs Arm. Its true thickness is uncertain because of folding and faulting; about 4 km of section is exposed along the type section whereas only 2 km of section is exposed north of Dark Hole in the western part of the map area.

Historical background

Williams (1963) included the lower sandstone and shale part of the Milliners Arm Formation in his map unit 8 and the upper conglomerate part in his map unit 9. Kay (1967) referred to these as the Sansom Graywacke and Goldson Conglomerate of his Dildo Sequence (1967).

Lithology

The Milliners Arm Formation consists of thinly to thickly bedded turbidites and marine resedimented conglomerates. Thinly bedded turbidites are common in its lower part and very thickly bedded conglomerates predominate in its upper part (Plate 71). This change defines an overall thickening and coarsening upwards sequence. The sandstones contain variable proportions of quartz, feldspar, and lithic grains; they contain rip-up clasts of shale in places also (Plate 72). Conglomerates contain a variety of clasts, most notably mafic to silicic volcanics, intermediate to silicic intrusive rocks, and variously colored cherts. Paleocurrents, as determined from sole marks and cross bedding (Plate 73), are from the northeast to north (Kay 1967; Watson 1981).

Several individual beds of conglomerate are traceable on airphotos for 3 km with no noticable change across Captain Jack's Island to New World Island. On the southern shore of Captain Jack's Island, a large erosional channel cuts into several underlying beds at a very low angle; it is barely perceptible on airphotos.

Structure and contacts

The Milliners Arm Formation is generally steep to overturned to the northwest, with cleavage less steeply dipping than bedding (Plate 74). Its lower part is locally strongly folded (Karlstrom and others 1982). At Fish Cove, a large climactic fold pair indicates a still larger anticline to the southeast and has a strongly attenuated, or sheared, southeast-facing limb. Boudinaged sandstone

Plate 71: Thick bedded conglomerates and turbidites, near top of Milliners Arm Formation, Mussel Cove. Duck Island is farthest to the left.

Plate 72: Thick sandstone bed, Milliners Arm Formation, Mussel Cove. Note shale rip-up clasts and parallel laminations.

Plate 73: Large scale cross bedding in thick bedded conglomerates, Milliners Arm Formation, Mussel Cove. Paleocurrents are from the north to northeast.

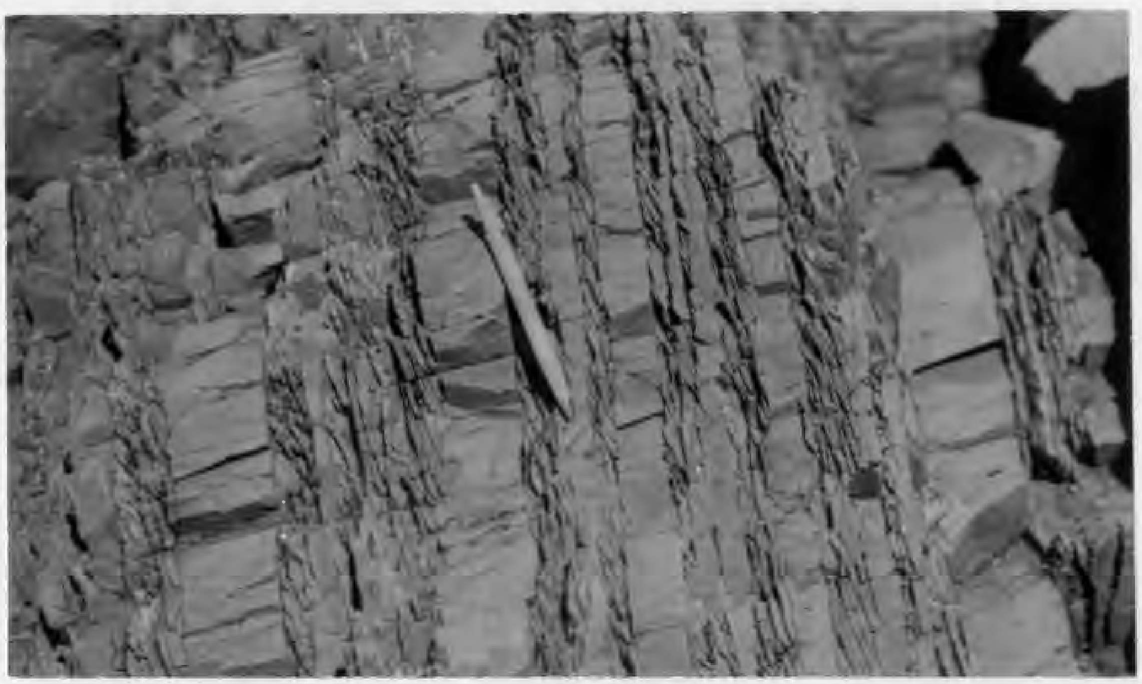

Plate 74: Interbedded sandstone and shale turbidites, Milliners Arm Formation, Mussel Cove. Beds face northwest to the left and cleavage indicates a syncline in that direction.

beds give the attenuated limb the appearance of melange or broken formation. Large scale repetition across the fold is indicated by repeated turbidite sections of mid-fan facies (Watson 1981) within the less deformed northwest-facing limbs.

Competent conglomerates in the upper part of the Milliners Arm Formation are broken along many faults and joints at oblique angles to bedding; e.g. small (1 m) blocks of conglomerate occur along the Mussel Cove Fault (Plate 56). About 1 km west of the Burnt Arm Fault, two of these oblique faults bound a block of conglomerate that has prominent topographic expression; despite its resemblance to "knockers" that have been taken for olistoliths, it is a late fault block.

Pre-cleavage folds in correlative rocks on southwestern New World Island verge southeast. Horne (1968) interpreted them to be slump folds indicating a southeast-dipping paleoslope.

The Milliners Arm Formation gradationally overlies Caradocian black graptolitic shales of the Dark Hole Formation (Horne 1969) near Joe Whites Arm, and elsewhere it may be faulted against the Dunnage Melange (Kay and Eldredge 1968). Its upper part is faulted against various strata in the New World Island Complex, including

Ordovician Squid Cove Volcanics and Silurian Muddy Cove shale. South-facing beds of Milliners Arm sandstone at the bottom of Mussel Cove indicate a syncline near the top of the Milliners Arm Formation south of the Cobbs Arm Fault.

Age and correlation

The age of the Milliners Arm Formation is now well constrained by its position above Caradocian graptolitic shale in the Dark Hole Formation and by middle Llandoverian brachiopods in a disturbed siltstone horizon in its upper part (Kay and Williams 1963; McKerrow and Cocks 1978). The Ordovician-Silurian boundary therefore lies somewhere in the middle of this conformable sequence.

The Milliners Arm Formation correlates with the Crow Head Formation, which is inferred to be the same age. As a mappable unit, the Milliners Arm Formation has never been extended beyond its 20 km length of outcrop on southeastern New World Island, but similar rocks to the west of Virgin Arm on southwestern New World Island are surely correlative.

Significance

The Milliners Arm Formation can be interpreted as having formed part of a submarine fan complex (Watson

1981). Distal thinly bedded turbidites at its base and proximal thickly bedded conglomerates at its top indicate fan growth and progradation. The fan probably faced southeast based on the paleoslope data of Horne (1968), and paleocurrents are locally parallel to the northeast-trending basin margin.

Provenance is readily determined from the conglomerates which indicate a source area of mainly igneous rocks and lesser oceanic sediments. Modern examples of this type of provenance are generally restricted to mature, dissected volcanic arcs. Detritus of the Milliners Arm Formation can be crudely matched with groups presently exposed in western Notre Dame Bay (Helwig and Sarpi 1969), which have been intepreted as island arc products (Williams 1979).

Conglomerate beds traceable for 3 km laterally indicate little facies variation with distance, particularly since the conglomerates are the most proximal lithology within the Milliners Arm Formation and would be expected to have the most variation laterally.

4.3 Crow Head Formation

Name, definition, distribution, and dimensions

The name Crow Head Formation is here applied to the 1 to 2 km thick section of clastic sediments that lies northwest of the New World Island Complex and southeast of the Clarkes Cove Fault. Its type section is along the shore of Burnt Cove from the fault bounding the New World Island Complex northwestwards towards Hillgrade. It is named after Crow Head Island, where it is also well exposed, about 1 km to the west in Burnt Cove. The Crow Head Formation extends eastwards as far as northeastern New World Island between Reddicks Cove and headlands to the north.

The western part of the Crow Head Formation includes a basal mainly sandstone unit about 800 metres thick overlain by about 200 metres of marine conglomerates near Hillgrade, and a shaly section south of Little Byrne Cove. The eastern part of the Crow Head Formation includes:

1) the same sandstone unit,

2) a thin shaly member which was called the Green Cove Formation by McKerrow and Cocks (1978) and is here referred to as the Green Cove member,

3) several hundred metres of gray and red conglomerates,

and

4) less than a hundred metres of shallow water quartzitic sandstone and shale referred to the Pike Arm member (Pike Arm Formation of Twenhofel and Schrock 1937).

Historical background

The Crow Head Formation was previously referred to map units 8 and 9 of Williams (1963), to the Sansom Graywacke and Goldson Conglomerate of the Cobbs Arm Sequence (Kay 1967), and to the middle part of the Big Muddy Cove Group (McKerrow and Cocks 1978). The turbidite part of the formation was lithically correlated with the Milliners Arm Formation (McKerrow and Cocks 1978), but McKerrow and Arnott (personal communication 1981) for a while thought that it was a distinctly younger unit. The Big Muddy Cove Group as originally defined by McKerrow and Cocks included the olistostromal assemblage of Ordovician and Silurian blocks enclosed in early late Llandoverian shale that lies above the Milliners Arm Formation and beneath their Goldson Group. Their usage is inappropriate, especially since Arnott (personal communication, 1981) demonstrated the stratified rather than chaotic heterogeneous nature of the Crow Head Formation, thus correcting the erroneous description by McKerrow and Cocks.

Lithology

The lowest mainly sandstone unit of the Crow Head Formation consists of turbidites, some thin bedded but mainly thick bedded. Bouma divisions A and E, or graded sandstones with sharp bases and overlain by shaly intervals, predominate (Plate 75). Paleocurrents are from the southwest (Arnott 1983). Some of the sandstone is relatively quartz rich and not true graywacke. A fist-size clast of black shale was found on the west shore of the island in Burnt Cove.

The Green Cove shale member contains Stricklandia brachiopods indicative of a deep shelf environment.

Gray conglomerates are polymictic and contain coralline limestone boulders near Hillgrade. Red conglomerates, which are more restricted in provenance , occur locally in the east. South of Clarkes Cove, red conglomerates contain ophiolitic detritus of basalt, diabase, red chert, gabbro, and minor serpentinized harzburgite.

Quartzitic sandstones and shales of the Pike Arm member exhibit shallow water characteristics, including the brachiopod E. curtisi. The sedimentology of the Crow Head Formation has been studied by Arnott (1983) in the eastern part of the map area.

Plate 75: Graded sandstone turbidites, Crow Head Formation, Burnt Cove.

Structure and contacts

The Crow Head Formation generally dips steeply south and faces north. It is much more complexly folded than the upper part of the Milliners Arm Formation immediately south of the New World Island Complex.

The basal contact of the Crow Head Formation with the New World Island Complex, not a simple feature, was discussed in Chapter V on structural relationships of the New World Island Complex. The Crow Head Formation is bounded to the northwest by the Clarkes Cove Fault. Structures within the Crow Head Formation are discussed from west to east. Many of these are related to larger structures that also affect the New World Island Complex.

On Crow Head Island, an overturned east-west trending horizontal syncline has axial plane cleavage. It is fairly tight with an interlimb angle of about 25 to 30 degrees. Axial plane faults with minor offset have slightly disrupted the core of the fold and can be directly attributed to the folding. Along one of these faults, north and south facing beds are juxtaposed and can be traced into the fold. The entire fold is truncated by the Lukes Arm Fault several hundred meters to the west, thus establishing post-cleavage movement along this major fault.

A parasitic metre-scale anticline within the north facing limb of the Crow Head Island syncline is microfaulted in its core (Fig. 28). A graded sandstone to shale bed is imbricated symmetrically about the axial plane which has produced a resemblance to cross bedding. The sense of movement on the microfaults is opposite that of normal parasitic structures. The cryptic unsheared nature of the microfaults is significant in that it demonstrates that hardrock deformation can generate structures resembling those in unlithified sediment.

On the large island in Burnt Cove, folds several metres across have axial plane cleavage (Plate 76). Their axial planes trend northeast and dip steeply southeast; their fold axes plunge northeast. They are not particularly asymmetric.

In the Hillgrade area, although there are no obvious fold closures on airphotos, there are several southeast-facing sections which indicate large climactic folds (Arnott and van der Pluijm, unpublished data, 1981). The enveloping surface must dip north because conglomerates at the top of the Crow Head Formation are not repeated farther southeast.

In the predominantly shaly section at Little Byrne Cove, beds dip steeply and face southwest along the

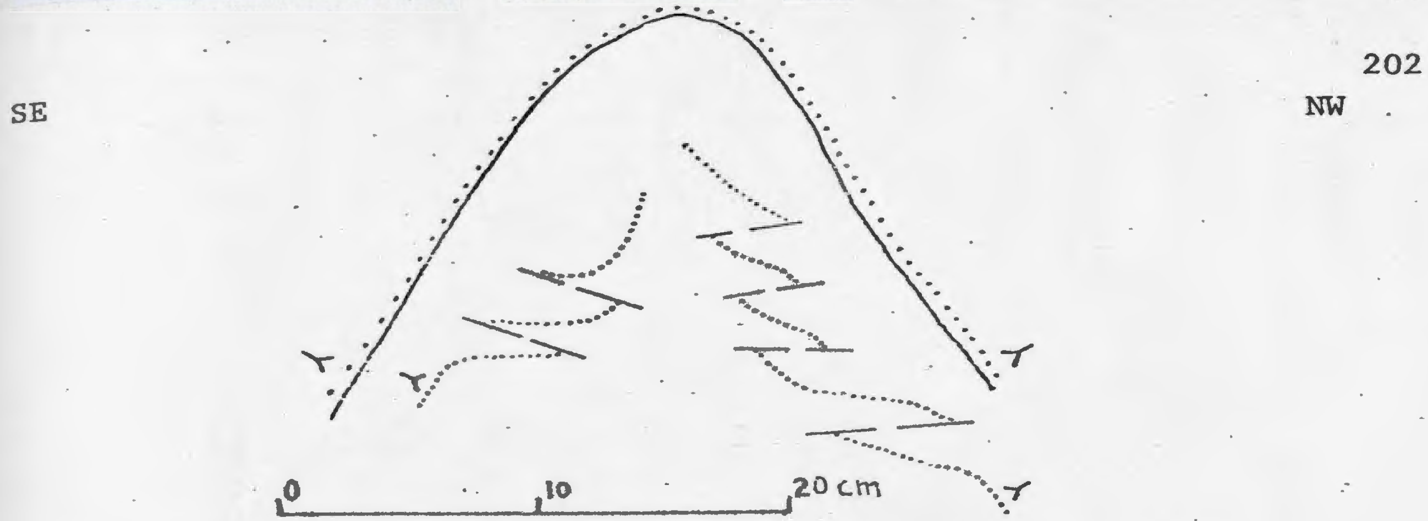

Figure 28: Small scale imbrication in upright climactic anticline (F2), Crow Head Island. Displacements of upward-facing graded sandy layers indicate cryptic faults. The overall structure, which is symmetrical about the axial plane, resembles sedimentary cross bedding, but formed during climactic (F2) folding. Also note that sense of displacement is opposite that of parasitic folds.

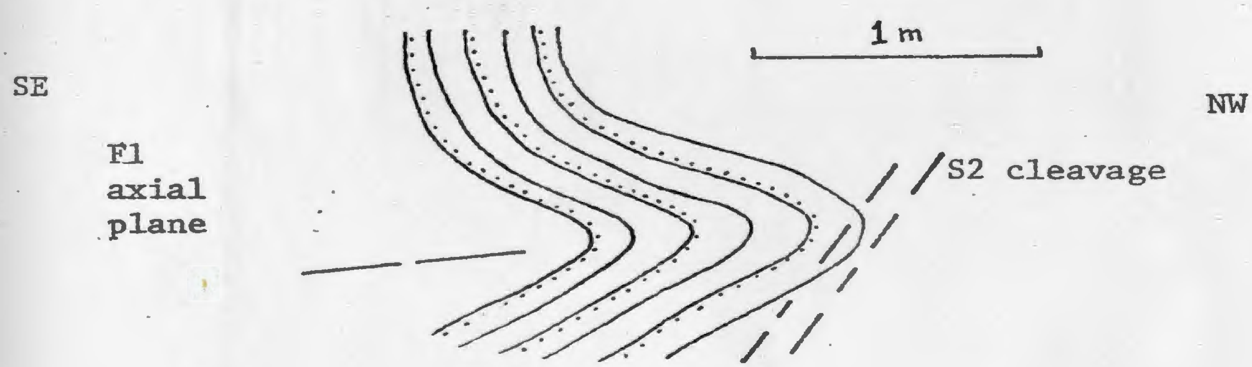

Figure 29: Pre-cleavage fold pair (F1), north side of road opposite main limestone quarry west of Cobbs Arm. S-asymmetry (as viewed) indicates vergence to the SE. Also note hinge shape asymmetry, angular anticline and rounded syncline.

Plate 76: Climactic folds with axial plane cleavage in Crow Head Formation, Burnt Cove. Anticline in foreground, syncline to right in background.

northwest flank of the Crow Head Formation. Cleavage dips less steeply than bedding, indicating a large pre-cleavage structure which is truncated by the Clarkes Cove Fault. Paul Williams (personal communication, 1982) correlated the predominantly shaly section here with the Dark Hole Formation based on lithologic resemblance, and interpreted a narrow structurally complex zone in Byrne Cove as a thrust placing the supposed Ordovician shales over Silurian conglomerates.

Along the northwest shore of Burnt Arm, the Crow Head Formation is much more deformed than in its type section along Burnt Cove. The significance of this anomalous deformation and its relationship to the Burnt Arm Fault, supposedly a rather minor fault, are uncertain.

Sandstones east of Burnt Arm are intensely broken by an array of joints and faults. Local southeast facing and also northwest-striking beds indicate complicated internal structure.

Southwest of Pikes Arm, conglomerates have been folded into a large (1 km) syncline, referred to as the Pikes Arm syncline. Cleavage that dips more steeply than bedding within its northwest limb in Clarkes Cove suggests that the syncline is an F2 climactic fold.

The Clarkes Cove Fault bounds the Crow Head Formation to the northwest and truncates the Pikes Arm syncline. A sliver of volcanic rocks occurs within Crow Head shales along the fault, and foliated limestone occurs at the margin of the volcanic fault block to the northwest. Spectacular quartz veins occur here in shales of the Crow Head Formation.

The Pikes Arm Syncline is displaced left laterally several hundred metres by the Mills Pond Fault, which follows an arcuate trajectory across the Crow Head Formation. Imbricated thin slices of sandstone about 1 km southwest of Pikes Arm also indicate sinistral displacement. A large boulder of flattened polymictic conglomerate with wafer-thin clasts was found along the fault trace immediately north of the New World Island Complex.

Along the Little Cobbs Arm Fault in Little Cobbs Arm, thin slices of sandstone are probably fault slices and are not olistoliths.

A pre-cleavage fold pair opposite the largest limestone quarry in Cobbs Arm consists of an angular northwest-facing nearly recumbent anticline northwest of an open and rounded syncline (Fig. 29). If effects of climactic steepening are removed, the asymmetry of hinge shape suggests incipient faulting of the anticline to the southeast.

In a road cut a hundred metres west of Muddy Cove, a recumbent anticline faces to the northwest and is probably transected by cleavage (Fig. 30). The hinge is broken parallel to the inverted limb. Adjacent northwest-facing beds suggest that the anticline is part of a southeast vergent fold pair, again indicating early transport to the southeast.

North of Muddy Cove on the road to Pikes Arm, south-dipping, north- facing beds are progressively overturned such that they are less steeply dipping than cleavage to the northwest (in the vicinity of the Little Cobbs Arm Fault). This tract of exceptionally overturned strata is difficult to explain. The geometry can be explained by early, pre-cleavage imbrication to the southeast followed by F2 steepening, rather than purely F2 folding of an excessively recumbent nature.

In Reddicks Cove, vertically plunging drag folds that affect cleavage indicate a sinistral sense of movement along the Reddicks Cove Fault.

Climactic fold pairs with Z-asymmetry (looking

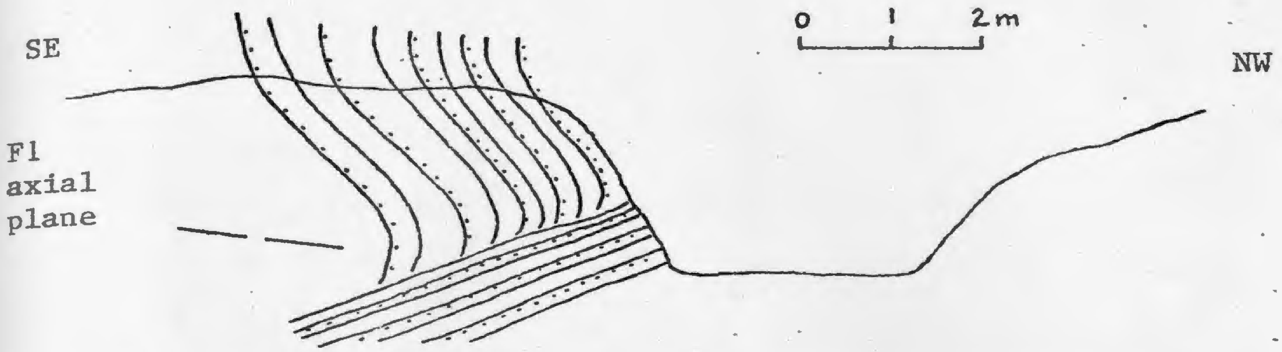

Figure 30: Pre-cleavage fold (F1), opposite church east of Cobbs Arm. Northwest-facing overturned anticline, broken at hinge. Short steeply dipping limb indicates S-asymmetry (as viewed) or vergence to the southeast.

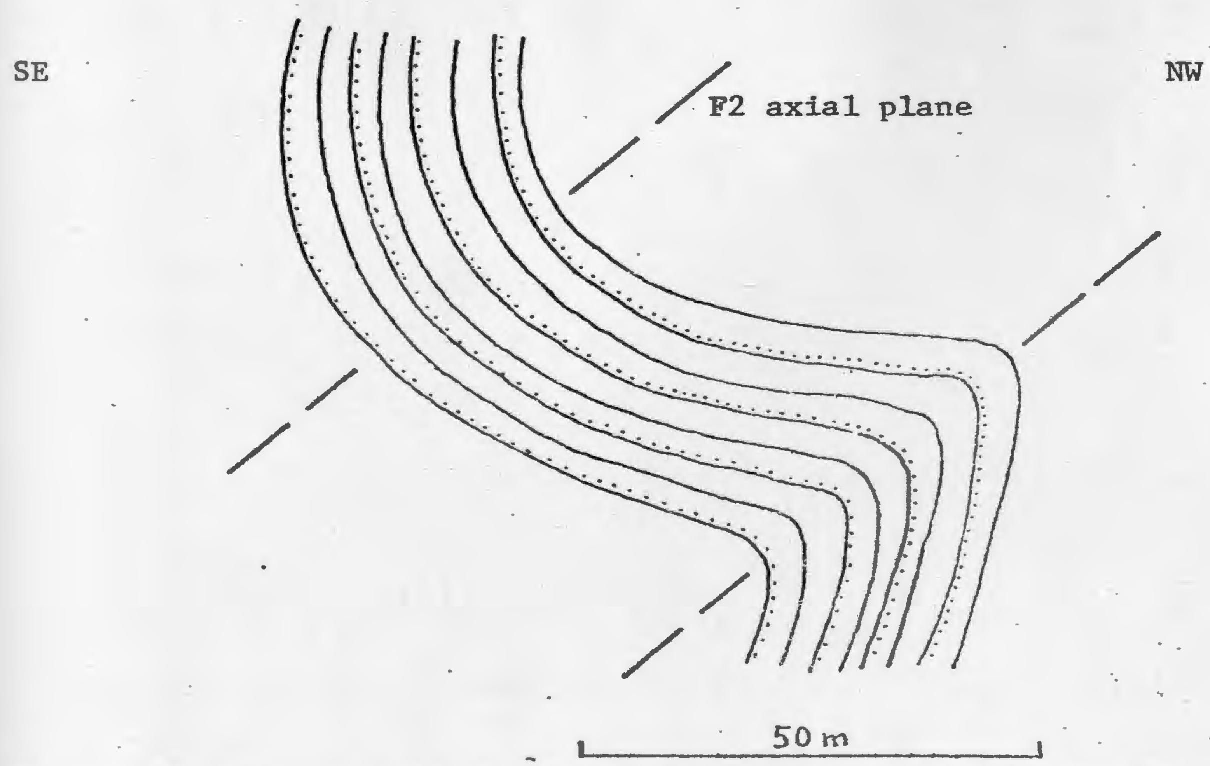

Figure 31: Climactic fold pair, north shore of Reddicks Cove. Angular anticline northwest of rounded syncline indicates sinistral asymmetry (as viewed) or larger anticline to the southeast.

northeast) occur along the north shore of Reddicks Cove (Plate 77). In one pair of folds, about 10 metres apart, an angular anticline lies north of a rounded syncline which suggests incipient breaking of the anticline and vergence to the southeast (Fig. 31).

A pocket of shale occurs along the northwest shore of Reddicks Cove. It is presumably Ordovician shale near the base of the Crow Head Formation that was squeezed between competent sandstone blocks rather than Silurian matrix in an olistostrome.

Southeast of Pikes Arm, several minor cross faults dissect conglomerates and have right lateral displacement, which is the only displacement of this sense known from the area.

Age and correlation

The age of the Crow Head Formation is critical to an understanding of the local geology. Harris (1966) thought the Crow Head Formation was Silurian because similar sandstone and shale within the New World Island Complex near Rogers Cove contains Silurian fossils and was viewed as unconformable on the Ordovician. Williams (1963) noted that the Crow Head Formation appeared to conformably overlie the Caradocian Rodgers Cove Shale and therefore its

Plate 77: Asymmetric climactic fold pair, Crow Head Formation, Reddicks Cove. Asymmetry indicates anticline to the southeast (right).

lower part was Ordovician. Arnott and McKerrow (personal communication, 1981) thought the Crow Head Formation was Silurian because it overlies the New World Island Complex which they interpreted as an olistostrome of early late Llandoverian age. Arnott and McKerrow later reverted to the view, similar to that of Williams (1963), that the Crow Head Formation and Rodgers Cove Shale are in stratigraphic contact; however, Arnott (1983) described the contact as a disconformity. Since rocks from both units are of deep water facies, a disconformity seems highly unlikely. There is now general agreement that the Crow Head Formation correlates with the Milliners Arm Formation (Karlstrom and others 1982; Arnott 1983), but, since the contact is a fault, an initially conformable section between the Rodgers Cove Shale and the Crow Head Formation remains an inference.

McKerrow and Cocks (1978) reported ages from two fossil localities in the basal sandstone unit of the Crow Head Formation. The first, along the road 1 km east of the Twillingate Highway junction, is uncertain but "more likely to be late Ashgill than Llandovery"; the second, along the west shore of Burnt Arm, is early Llandoverian (Plate 78). The shaly member northwest of Cobbs Arm, or Green Cove Formation of McKerrow and Cocks (1978) contains Stricklandia lens progressa of early late Llandoverian age. Limestone clasts with Silurian corals occur in the

Plate 78: Brachiopod in sandstone from Crow Head Formation, west shore of Burnt Arm. Early Llandovery age reported by McKerrow and Cocks (1978) makes Crow Head and Milliners Arm Formations correlative.

conglomerate section at the top of the Crow Head Formation near Hillgrade (Williams 1963). The Pike Arm member contains the youngest fossils, E. curtisi brachiopods , of Telychian age.

Assuming the Crow Head Formation is constrained in age by Caradocian graptolites of the Rodgers Cove Shale, it correlates with the Milliners Arm Formation to the south of the New World Island Complex and the Muddy Cove Clastics within the New World Island Complex. Upper portions of the Crow Head Formation correlate with the Indian Cove Formation. The Crow Head Formation also correlates with the Indian Islands Group to the east (Karlstrom 1982) and Sansom and Point Leamington Graywackes to the west.

Significance

The predominance of Bouma division AE beds in turbidites of the Crow Head Formation suggests proximal deposition. The black shale clast in the lower part of the Crow Head Formation is significant in that it correlates with the underlying Rodgers Cove Shale, which apparently must have been locally uplifted and subjected to erosion while the Crow Head Formation was being deposited elsewhere.

Green Cove shales, based on the occurrence of

Stricklandia brachiopods, were deposited on a deep shelf.

Red conglomerates have a limited assemblage of coarse clasts derived locally from a partly ophiolitic source. The coarse ophiolitic detritus indicates a truly orogenic source area that was close by; previous workers (Helwig and Sarpi 1969) detected only igneous and sedimentary detritus suggesting a dissected, but undeformed, volcanic arc source.

Shelf deposits of the Pike Arm member indicate the sequence shallows upwards. According to the work of McKerrow and Cocks (1978), these deposits are slightly younger (Telychian) than the youngest (Fronian) deposits in the New World Island Complex. The Fronian brachiopods in the New World Island Complex are thought to date syn-sedimentary thrusts; if the precision of the dates can be trusted, the Pike Arm member was being deposited (conformably) above the thrust sheet that was providing detritus to Muddy Cove breccias. This corollary of a syn-sedimentary thrust model is somewhat alarming, but it does suggest a mechanism for the shallowing-upwards sequence of the Crow Head Formation, that is crustal thickening from below.

4.4 Byrne Cove Melange

Byrne Cove Melange is a name used by Arnott (1983) for chaotic rocks that occur in a belt from Little Byrne Cove to Clarkes Cove. Volcanic slices in shale occur at both Little Byrne Cove and Clarkes Cove (Map 1). Its distribution is along the Clarkes Cove Fault between the Crow Head Formation and Clarkes Cove Volcanics. The fault and melange both truncate the Crow Head Formation and also the Pikes Arm syncline, an F2 climactic fold. The Byrne Cove Melange is younger, and therefore cannot possibly be a lateral correlative of sandstone and shale within the Crow Head Formation as shown by Arnott (1983, Fig. 2).

The Byrne Cove Melange includes rocks of the Clarkes Cove Volcanics and rocks from various horizons in the Crow Head Formation, notably Green Cove shale. Conglomerates containing large sandstone boulders (Arnott 1983) do not have the same significance as shaly conglomeratic breccias from the New World Island Complex; i.e. they do not contain large angular fragments derived from rocks of the adjacent fault block.

4.5 Indian Cove Formation

The Indian Cove Formation was named by McKerrow and Cocks (1978) for exposures of red conglomerates on the peninsula between Indian Cove and Little Byrne Cove. Red conglomerates at Clarkes Cove and to the north and eastward to Herring Head and overlying red sandstones on Burnt Island are also assigned to the Indian Cove Formation. It includes over 100 m of red conglomerates at its base, minor shale in Goshens Arm, a thin red sandstone unit on Burnt Island, and overlying red conglomerates. The Indian Cove Formation is less than 1 km thick.

Lithology

The red conglomerates that constitute the bulk of the Indian Cove Formation contain abundant volcanic clasts, some up to 1 meter and more across. Shale in Goshens Arm, probably interbedded with the conglomerates, contains *Pentamerus* brachiopods, which indicate a slightly less deep shelf environment than *Stricklandia* (McKerrow and Cocks 1978). Overlying red sandstones on Burnt Island, with shallow water *E. intermedia* brachiopods, contain contemporaneous volcanic ash.

Structure and contacts

The Indian Cove Formation is disposed in a tight syncline whose axis trends northeast through Burnt Island. Karlstrom and others (1982) interpreted this as a pre-cleavage fold, but have had later doubts (van der Pluijm, personal communication, 1983).

At Green Cove, the Indian Cove Formation unconformably overlies Ordovician volcanic rocks, which are assigned to the Clarkes Cove Volcanics (Plate 79). Its basal contact is not exposed along Burnt Arm or at Little Byrne Cove; at Little Byrne Cove, the presence of Rodgers Cove Shale indicates that if the basal contact here is also an unconformity, it is less profound than at Clarkes Cove.

Age and correlation

Silurian corals occur in the base of the Indian Cove Formation at Clarkes Cove (Plate 80). Brachiopods in overlying sandstone on Burnt Island are early late Llandoverian (McKerrow and Cocks 1978). The Indian Cove Formation correlates with upper parts of the Crow Head and Milliners Arm Formations.

Significance

Large clast size and restricted provenance of the

Plate 79: Disconformity at base of Indian Cove Formation, Clarkes Cove. Silurian sandstone with pebbly lag rests on basalt of pre-Caradocian Clarkes Cove basalt.

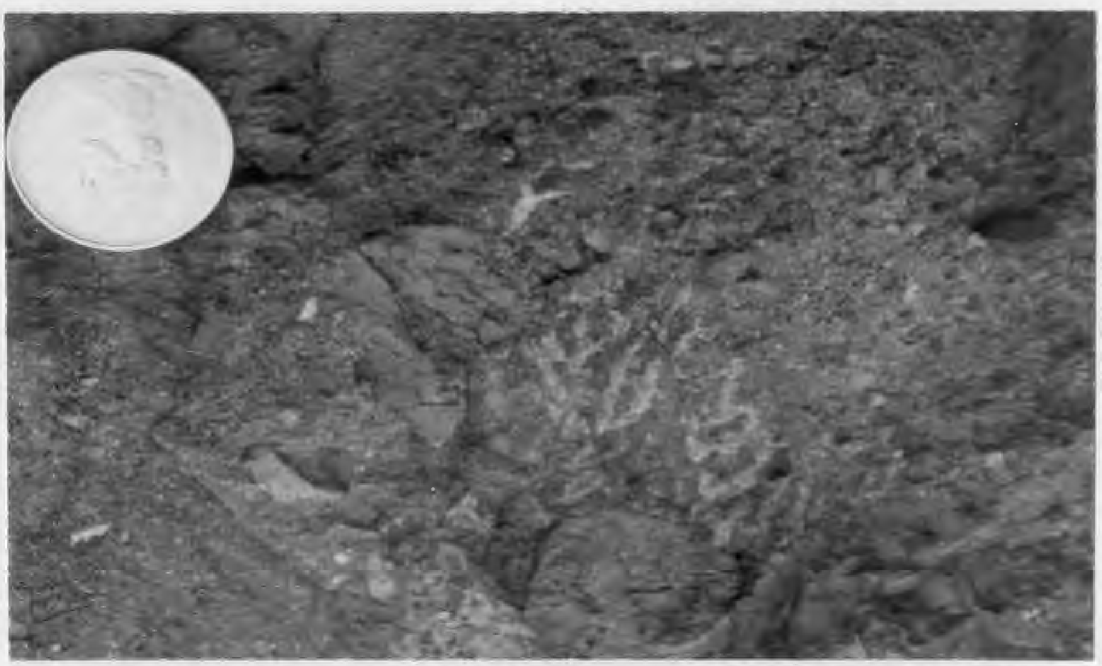

Plate 80: Silurian corals in basal pebbly sandstone of the Indian Cove Formation, Clarkes Cove.

Indian Cove Formation indicate that it had a local source. Volcanic ash also indicates nearby contemporaneous volcanic activity. The basal unconformity, preponderance of redbeds, and fauna indicate it was deposited near a basin margin.

4.6 Comparison of flysch formations

The various flysch sections of eastern New World Island (Miliiners Arm, Muddy Cove, Crow Head, and Indian Cove Formations) are linked at their bases by the Caradocian shale (Fig. 4). They were probably all deposited in a single, continuous basin (Fig. 32).

The sequence is mainly regressive, that is all sections shallow and coarsen upwards from black shales to proximal conglomerates (the base of the Indian Cove Formation records a minor transgression over eroded Ordovician volcanic rocks).

The basin may have been disrupted by faulting late in its history (early late Llandoverian time), but there is little evidence to support Arnott's (1983) model of alternating basins and emergent areas, e.g.

1) the chaotic rocks that prompted Arnott's suggestion of syn-sedimentary faulting throughout Upper Ordovician to late Llandoverian time do not appear until late Llandoverian time;

2) there is a continuous asymmetric transition of sedimentologic and stratigraphic features from section to section rather than reversals symmetrically distributed about Arnott's postulated source areas;

3) conglomerate beds traceable for 3 km indicate that

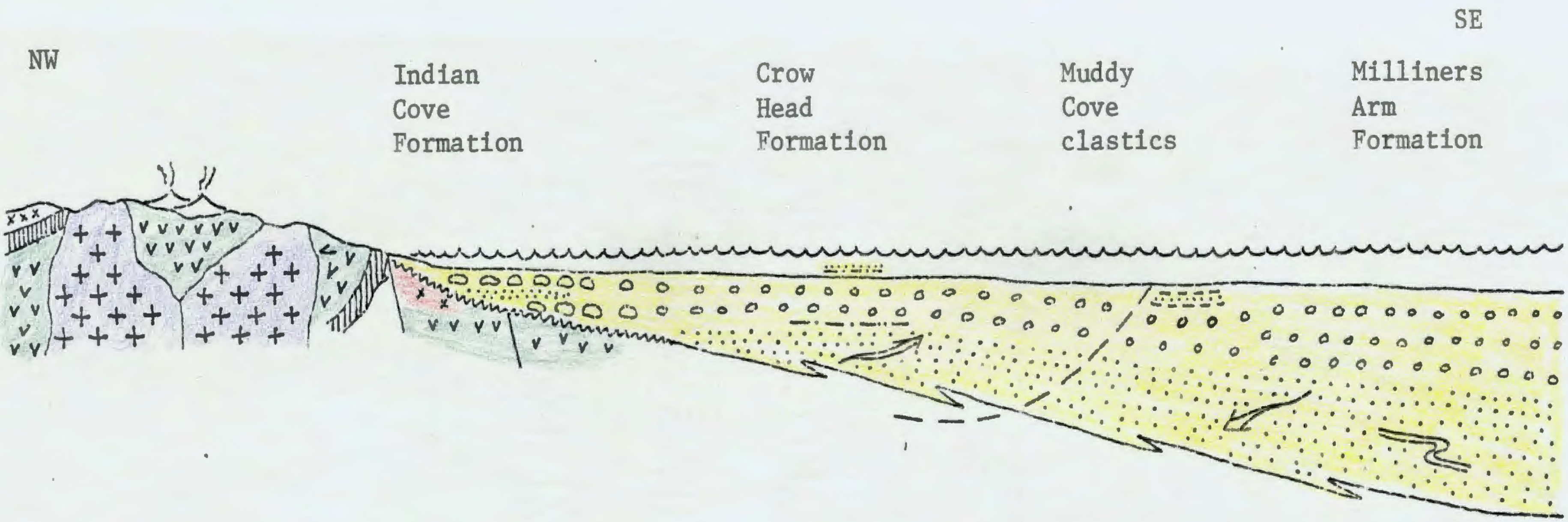

Figure 32 : Interpretation of flysch basin geometry during early late Llandoverian time, eastern New World Island.

facies are relatively constant with distance as opposed to the rapid and variable facies changes postulated by Arnott.

The Indian Cove Formation was deposited closest to and the Milliners Arm Formation farthest from the basin margin, based on:

1) the Indian Cove Formation rests unconformably above Clarkes Cove Volcanics whereas formations to the southeast overlie Ordovician pelagic deposits conformably; the unconformity exposed at Clarkes Cove must die out somewhere in between;

2) for a given age, formations to the northwest include a greater proportion of rocks of shallow water facies as indicated by sedimentary structures (e.g. proximal AE turbidites of the Crow Head Formation vs. more distal turbidites of the Milliners Arm Formation) and by fossils (Eocelia and Pentamerus communities of the Indian Cove and Crow Head Formations vs. Stricklandia community of the Crow Head and Muddy Cove Formations);

3) the Indian Cove Formation contains the largest boulders (1+ m) in the area; and

4) an increase in thickness to the southeast suggests that the basin was deeper in that direction.

Each flysch formation lies within a different structural slice. Slices presently towards the northwest initially lay in that direction based on provenance of sandstones and conglomerates, paleoslope, and, to a lesser extent, on paleocurrent and age data.

1) A clast assemblage of predominantly igneous rocks (dacite, basalt, andesite, tonalite), including minor, but locally derived, ophiolitic debris, indicates a partially dissected island arc source area, The most reasonable choice for such a source area is the island arc terrane of western Notre Dame Bay, a view held by most workers (e.g. Helwig and Sarpi 1969; Dean 1978; Nelson 1981). Contemporaneous volcanic ash in the Indian Cove Formation may derive from the Silurian (?) Cape St. John Group. An eastern source area is less likely because it is not known if ophiolites were obducted by this time along the Gander River Ultrabasic Belt and, even if there are Ordovician island arc volcanic rocks to the east, they would have been covered by Silurian volcanic rocks of the Botwood Group.

2) Several pre-cleavage folds suggest a southeast-facing paleoslope, in agreement with measurements by Horne (1968) on southwestern New World Island.

3) Paleocurrents are highly variable, e.g., from the north and northeast in the Milliners Arm Formation and from the southwest in the lower Crow Head Formation; however, none are from the southeast. They can be interpreted as longitudinal currents parallel to a northeasterly-trending basin margin. Longitudinal currents are a common attribute of other turbidite successions.

4) Dean (1978) suggested that the base of flysch sections is younger to the southeast, indicating progradation in that direction.

In summary, flysch sections of New World Island represent different parts of a southeast-facing clastic prism with a source area to the northwest in the Taconic arc-continent collision zone.

4.7 Summary of structural relationships of nearby units

1. The Milliners Arm Formation, Crow Head Formation, and Indian Cove Formation underlain by Rodgers Cove Shale and Clarkes Cove Volcanics constitute the three largest continuous blocks on eastern New World Island. They are separated by two chaotic zones, the New World Island Complex and Byrne Cove Melange, that comprise numerous smaller elements.

2. The Byrne Cove Melange comprises volcanic slices in shale at Little Byrne Cove and at Clarkes Cove. Its distribution coincides with the Clarkes Cove Fault, which truncates the entire Crow Head Formation and an F2 fold, the Pikes Arm syncline. Sheared basalt, foliated limestone in the southeasternmost Clarkes Cove Volcanics, and quartz veins in adjacent shale also occur along the Clarkes Cove Fault. It is possible that slices of chaotic sediments are incorporated along the fault, but this writer is not aware of any.

3. The asymmetry of two small-scale pre-cleavage folds near the base of the Crow Head Formation suggests that earliest transport was towards the southeast. A large pre-cleavage fold southeast of Little Byrne Cove is truncated by the Clarkes Cove Fault.

4. Most pre-cleavage folds are synclines and, where fold pairs occur together, the anticline is either angular or broken. They may have formed as drag folds beneath thrusts that cut upwards through gently dipping beds. F2 folds

also include more synclines than anticlines.

5. Faulting in the area was continuous from syn-sedimentation (New World Island Complex) through post-F2 folding (Clarkes Cove Fault). The distribution of F2 folds and faults suggests the two are related, e.g.:

1) at Fish Cove in the Milliners Arm Formation, the southeast-facing limb of a large fold is sheared (Karlstrom and others 1982).

2) at Mussel Cove, an F2 syncline at the top of the Milliners Arm Formation also has a sheared southeast-facing limb; the adjoining anticline in Cobbs Arm folds the New World Island Complex; the Cobbs Arm Fault between the two was thought by Arnott (1983) to truncate these folds, but the syncline at the top of the Milliners Arm Formation may be a contemporaneous drag fold along the fault.

3) on Crow Head Island, the axial plane of an F2 syncline is faulted slightly; it suggests that faults with greater displacement might have a similar origin; a complex parasitic structure resembles sedimentary cross-bedding but is purely of tectonic origin.

4) the Pikes Arm syncline at the top of the Crow Head Formation is sheared off by the Clarkes Cove Fault.

6. The asymmetry of F2 folds is predominantly Z (looking northeast), e.g. at Fish Cove, Mussel Cove, north of Reddicks Cove, Pikes Arm, Crow Head Island, and Hillgrade. If F2 folds are related to thrust (or higher angle reverse) faults, their vergence also indicates a southeast-directed

4

polarity.

7. The Burnt Arm and related cross faults cut all earlier structures, and related drag folds affect cleavage (Fig. 33). The Lukes Arm Fault is included with these faults because it truncates a major F2 syncline on Crow Head Island at a fairly large angle. Displacement on these faults is left-lateral except for several small right-lateral displacements southeast of Pikes Arm (Fig. 33). The Lukes Arm and Reach Faults may also be major left-lateral strike-slip faults controlling the pattern of these small left (synthetic) and right (antithetic) displacements.

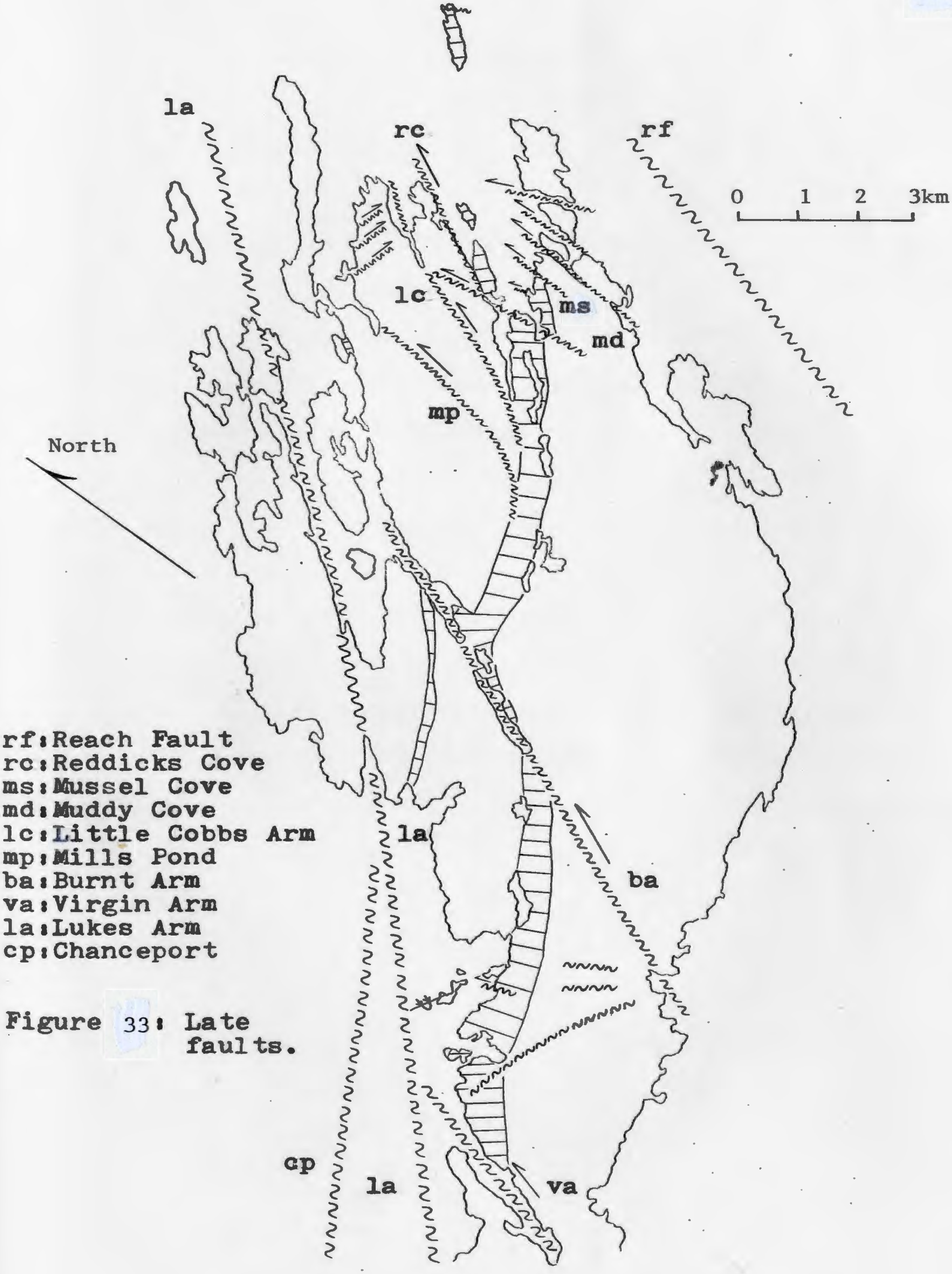

Figure 33: Late faults.

CHAPTER V

CONCLUSIONS

The following chapter summarizes important features of the New World Island Complex and nearby formations, incorporates them in a syn-sedimentary thrust model, and discusses several important implications for the regional geology of northeast Newfoundland.

5.1 Summary

1. Eastern New World Island is composed of three large slices, the Milliners Arm, Crow Head, and Indian Cove, separated by two chaotic zones, the New World Island Complex and Byrne Cove Melange, comprising many smaller elements. In the New World Island Complex, some of the smaller elements may be fragments in chaotic sedimentary deposits, but most elements are separated by fault contacts.

2. Volcanic rocks within blocks of the New World Island Complex are geochemically distinct from modern island arc lavas and may have formed in an open ocean setting.

3. Clastic sections (Milliners Arm, Muddy Cove, Crow Head, and Indian Cove Formations) are linked by Caradocian shale

at their base. There is little variation within slices compared to between them.

4. The Indian Cove Formation was deposited closest to a basin margin and unconformably overlies pre-Caradocian volcanic rocks, whereas formations to the southeast conformably overlie Caradocian pelagic shales.

5. Paleocurrents from every direction but the southeast, pre-cleavage fold asymmetry, and provenance suggest that the source area for clastic sections was to the northwest in the Taconic arc-continent collision zone.

6. A single southeast-facing basin is suggested by the linking Caradocian shale and continuous asymmetric transition in sedimentologic character from the Indian Cove Formation to the Milliners Arm Formation. This basin was disrupted by faulting late in its history.

7. Chaotic sedimentary breccias in the New World Island Complex contain clasts of black shale and limestone that correlate with the stratigraphic section in adjacent fault blocks (Rodgers Cove Shale, Cobbs Arm Limestone). Also, one clast of limestone is inhomogeneously deformed, suggesting syn-sedimentary faulting.

8. Highly mobile Silurian shale intrudes fragmented

Ordovician limestone, suggesting that the limestone was lithified but the shale was not. Differentiation of the shale to a more cherty composition inward along dikes suggests that the limestone was juxtaposed with the shale slowly at rates more compatible with tectonic processes than with slumping.

9. Faults appear to have been folded by climactic (F2) folds with axial planar cleavage in three places.

10. Climactic (F2) folds are transected by related faults elsewhere.

11. Higher slices presently to the northwest initially lay to the northwest (see section 4.6) and were thrust to the southeast. Asymmetry of folds and the sense and displacement of faults also suggests southeast-directed thrusting.

12. All structures in the area are dissected by steeply dipping, rectilinear faults. Faults of this group oriented at a small angle to the Lukes Arm Fault have left lateral displacement, whereas those oriented at a large angle have right lateral displacement, suggesting they are synthetic and antithetic faults related to the Lukes Arm Fault.

5.2 Model

Most of the features described herein fit the concept that New World Island Complex formed by syn-sedimentary and continuing faulting that telescoped a southeast-facing basin.

Pre-Caradocian volcanic rocks in the New World Island Complex may have been erupted outboard of the island arc that collided with North America during the Middle Ordovician Taconic Orogeny, or they may represent an eastern facies of the arc itself.

Caradocian shales transgressed the volcanic edifice. They were followed by a major regressive sequence of clastic sediments derived from a source area in the collision zone to the west. The Silurian regressive sequence coarsens and shallows upward and is punctuated by deposition of chaotic sedimentary breccias.

The breccias were derived from Ordovician sections exposed in thrust sheets advancing towards the southeast (see section 5.1, 11.). (It is possible the breccias were derived from normal faults developed late in the history of the basin, but none are observed in the thrust sheets presently exposed). Lithified Ordovician rocks were juxtaposed with muddy sediments and incorporated as blocks within them along the line of these faults.

Early displacement was considerable along these faults and juxtaposed stratigraphic sections that were initially far removed.

Early faults were folded, and cleavage developed within fault blocks. Continued faulting, at a steeper angle, locally truncated the earlier folds.

This structural history is similar to modern accretionary prisms in that faulting, which underplated outboard slices from the southeast, occurred continuously through more than one generation of folding. Melanges are developed to a lesser degree, probably because thick sections of competent rocks are predominant in the stratigraphy.

Following this major orogenic episode, the area was dissected by numerous strike-slip faults related to a major left lateral shear.

Regional implications and correlations

1. No pre-Silurian unconformities are known from the Dunnage Zone between New World Island and the eastern Davidsville Group, suggesting an extensive basin even after the Ordovician, Similar basins probably underlain by undeformed oceanic crust in the Silurian also occur along strike in the Maine Slate Belt, Fredericton Trough, and Southern Uplands of Scotland.

2. Silurian melanges developed in this basin also occur along strike from the New World Island Complex. The Boones Point and Sops Head Complexes to the west in Notre Dame Bay are direct correlatives of the New World Island Complex. They are localized at the top of flysch sections and to the south of faults that bound the Roberts Arm Belt of marine volcanic rocks. They contain sediments like the Muddy Cove shaly conglomeratic breccias and have also been related to syn-sedimentary thrusting directed towards the southeast.

3. Other melanges in the Dunnage Zone are not necessarily, as most commonly assumed, pre-Caradocian in age; they could be related to post-Caradocian thrusting.

3a. Could the Dunnage Melange, for example, include rocks younger than pre-Caradocian? Internally, the Dunnage Melange includes black shales, polymictic conglomerates, and micaceous sandstones which, although unfossiliferous, strongly resemble Caradocian shales, Silurian "Goldson" conglomerates, and Silurian "Botwood" sandstones (James Hibbard, Harold Williams, and Paul Dean, respective personal communications, 1982); the micaceous sandstones are of particular interest because they are anomalous compared to Ordovician sandstones everyplace else in Notre Dame Bay; peripherally, Caradocian through Llandoverian rocks on Upper Black Island, Knight's Island, Farmer's Island, and southwestern New World Island can be treated as blocks within the Dunnage Melange; the rocks on southwestern New World Island are directly on strike from the Dunnage Melange even after 2 km displacement along the Virgin Arm Fault is restored (assuming the volcanic belt through Lukes Arm is a continuation of the New World Island Complex).

The Dunnage Melange is reported to have a "conformable" upper contact with Caradocian shale (Hibbard and Williams, 1979), which has been argued to imply a pre-Caradocian age. The northwestern contact of the New World Island Complex is analogous to the northwestern contact of the Dunnage Melange in that Caradocian matrix of the New World Island Complex is inferred to have been conformable with northwest-facing sandstone turbidites to the northwest; however, elsewhere in the New World Island Complex, matrix is Silurian. Also, any melange composed of blocks and disrupted matrix, whether olistostromal or tectonic, should have a discordant upper contact with overlying stratified sediments. Such a "conformable" contact is not considered a valid criterion for a pre-Caradocian age.

Although the Dunnage Melange includes chaotic sedimentary features, as does the New World Island Complex, it is also locally sheared (James Hibbard, personal communication,1982; cf. Hibbard and Williams 1979, p.1013, in section "Soft-rock deformation")and its chaotic sedimentary features do not necessarily imply that the melange as a whole is entirely of surficial origin. Perhaps the Dunnage Melange is not a pre-Caradocian olistostrome, but is underlain by younger rocks and is related to post-Caradocian thrusting.

3b. Farther to the east, the Carmanville and other shaly melanges in the Davidsville Group have been correlated with the Dunnage Melange. These are conformably overlain by stratified Silurian clastic rocks, thus excluding the possibility of pre-Silurian deformation. In the Dunnage Zone generally, there is a close correspondence between the occurrences of both melanges and shale. Perhaps the extreme incompetence of the shales controls the distribution of melanges. In support of a thrust-related origin for these melanges is a possible window of continental volcanic rocks through the Dog Bay Melange in the core of a large antiform (see map by Karlstrom 1982).

4. Ordovician and Silurian strata of the Dunnage Zone are faulted top and bottom. Rock groups of the same age but of markedly different facies are commonly juxtaposed, implying distant transport along faults.

Several kilometres of structural burial, which is geometrically feasible only by thrusting, is indicated by the development of a penetrative cleavage, metamorphic grade (Franks 1974), and by extrapolating present erosion rates. A thick crust also underlies the Dunnage Zone, as indicated by seismic data, its present elevation, gravity, and granitic intrusions and felsic dikes; bimodal volcanic rocks and the Silurian regression suggest that crustal thickening was well under way in the Silurian.

5. Known thrust faults in the Dunnage Zone are, with the possible exception of ones in southwest Newfoundland, southeast-directed:

1) Point Rousse ophiolite thrust over rocks to the southeast;

2) ophiolitic Lushs Bight Group thrust over the Springdale Group to the southeast;

3) southeast-directed thrusts in a belt coincident with the Sops Head, Boones Point, and New World Island Complexes;
4) Pipestone Pond and Coy Pond Complexes and volcaniclastic cover thrust from the northwest over quartzitic clastic rocks to the southeast;
5) Gander River Ultramafic Belt and overlying Davidsville Group thrust over quartzitic clastic rocks;
6) volcaniclastic rocks in the Gander Zone thrust over quartzitic clastic rocks; and
7) thrusts in southwestern Newfoundland, bracketed by dated intrusions as Silurian (Chorlton 1982).

6. The geologic section of New World Island has many similarities to the Southern Uplands of Scotland, including thrust sheets of post-Caradocian flysch underlain by Caradocian and older volcanic rocks, which are predominantly northwest-facing and are asymmetrically folded with Z-asymmetry (looking northeast). Unlike in the Southern Uplands, however, an age progression of younger thrusts to the southeast cannot be demonstrated across the Dunnage Zone. Nevertheless, the preponderance of southeast-directed thrusts in the Dunnage Zone suggests a general correlation with the Southern Uplands.

In the Southern Uplands, volcanic rocks, intrusions, and metamorphic events to the northwest have been related to the northwest-dipping subduction inferred from the southeast-directed thrusts. In Newfoundland, similar calc-alkaline volcanic rocks, intrusions, and metamorphism are most commonly related to waning effects of the much earlier Middle Ordovician Taconic arc-continent collision, but perhaps they are in part due also to northwest-dipping subduction during the Silurian.

The Squid Cove Volcanics are geochemically distinct from typical modern island arc lavas. A Southern Uplands model for the Dunnage Zone would fit well with an interpretation of the Squid Cove Volcanics as open ocean rather than island arc-related volcanic rocks.

7. A final argument in support of major southeast rather than northwest-directed thrusting is that the Taconic collision zone to the northwest would have acted as a major obstacle to thrusting in that direction.

8. The Lukes Arm and Reach Faults are late faults that truncate major folds and Acadian granites. Correlative rocks of different facies in intervening fault blocks (Herring Neck Group and Clarkes Cove Volcanics; Milliners Arm Formation and Indian Islands Group) and a sharp geophysical gradient across the Lukes Arm Fault (dense, magnetic crust of igneous rocks to the northwest) suggest considerable displacements along the faults, which supports strike-slip rather than normal movement.

Smaller scale faults that have left lateral and right lateral displacements are probably related to the large scale faults; the left lateral faults would then be synthetic, the right lateral faults would be antithetic, and the large scale faults would have left lateral displacements.

Late faults with left lateral displacements are known from southwestern Newfoundland (Chorlton, personal communication, 1982), from Scotland (Great Glenn Fault), and are indicated by paleomagnetic data (Kent and Opdyke 1979).

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MAP 2: ROGERS COVE, JOEYS COVE, MUSSEL COVE AREA

LEGEND

SILURIAN AND UPPER ORDOVICIAN

| 4 | 5 | 6 | MUDDY COVE CLASTICS: 4, INTERBEDDED QUARTZITIC GREYWACKE AND GREY SHALE; 5, MAINLY GREY SHALE, MINOR THIN SANDSTONE INTERBEDS; 6, SHALY CONGLOMERATIC BRECCIA

MILLINERS ARM FORMATION (TO SOUTHEAST):
15, INTERBEDDED QUARTZITIC GREYWACKE AND SHALE;
16, GREY POLYMICTIC CONGLOMERATE

MIDDLE ORDOVICIAN (CARADOCIAN)

3 RODGERS COVE SHALE: INTERBEDDED BLACK, GRAPTOLITIC SHALE AND CHERT; 3A, MINOR ARGILLACEOUS LIMESTONE

MIDDLE ORDOVICIAN (LLANDEILIAN)

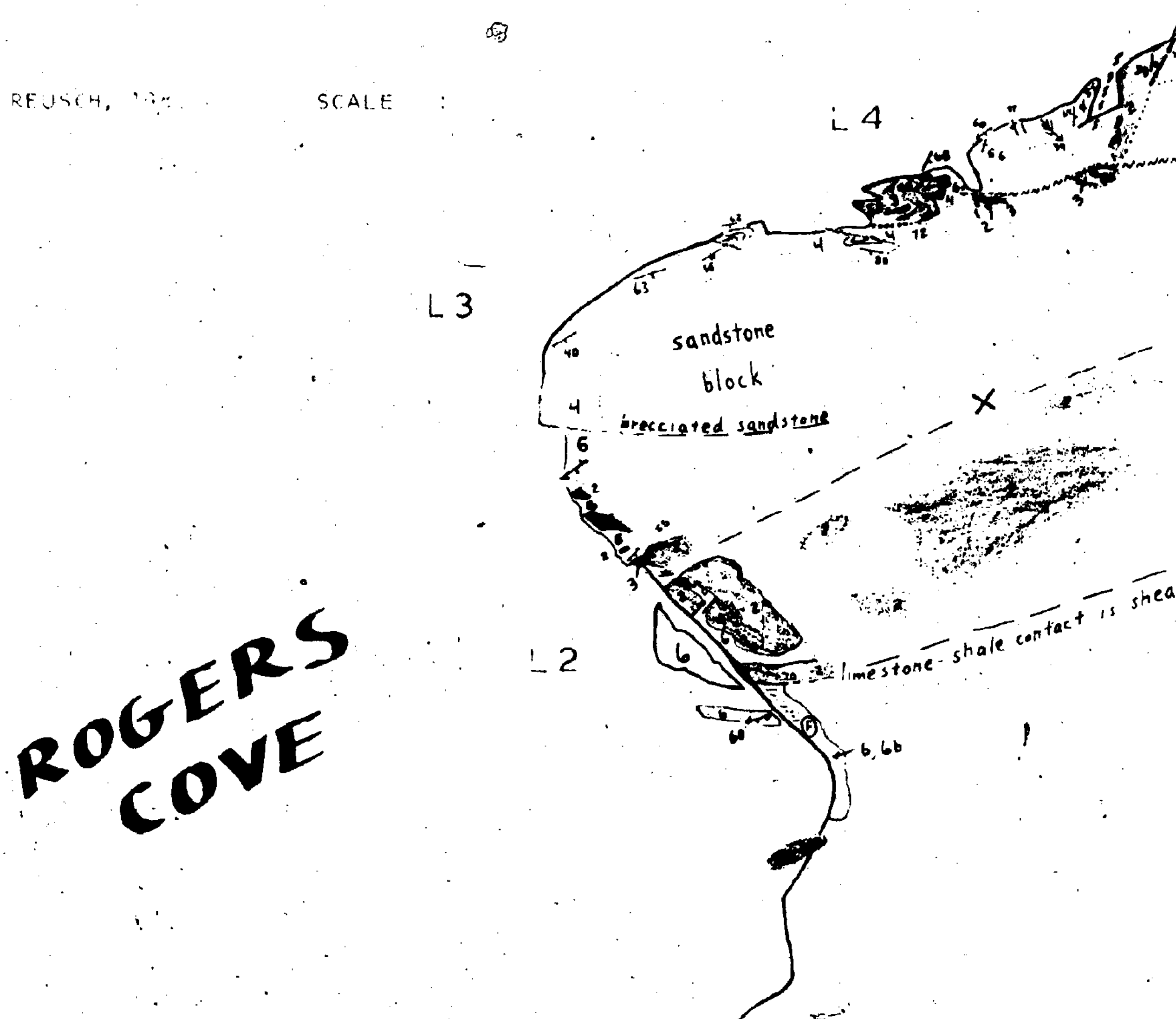
2 COBBS ARM LIMESTONE: GREY LIMESTONE, CRINOID COLUMNS ABUNDANT LOCALLY

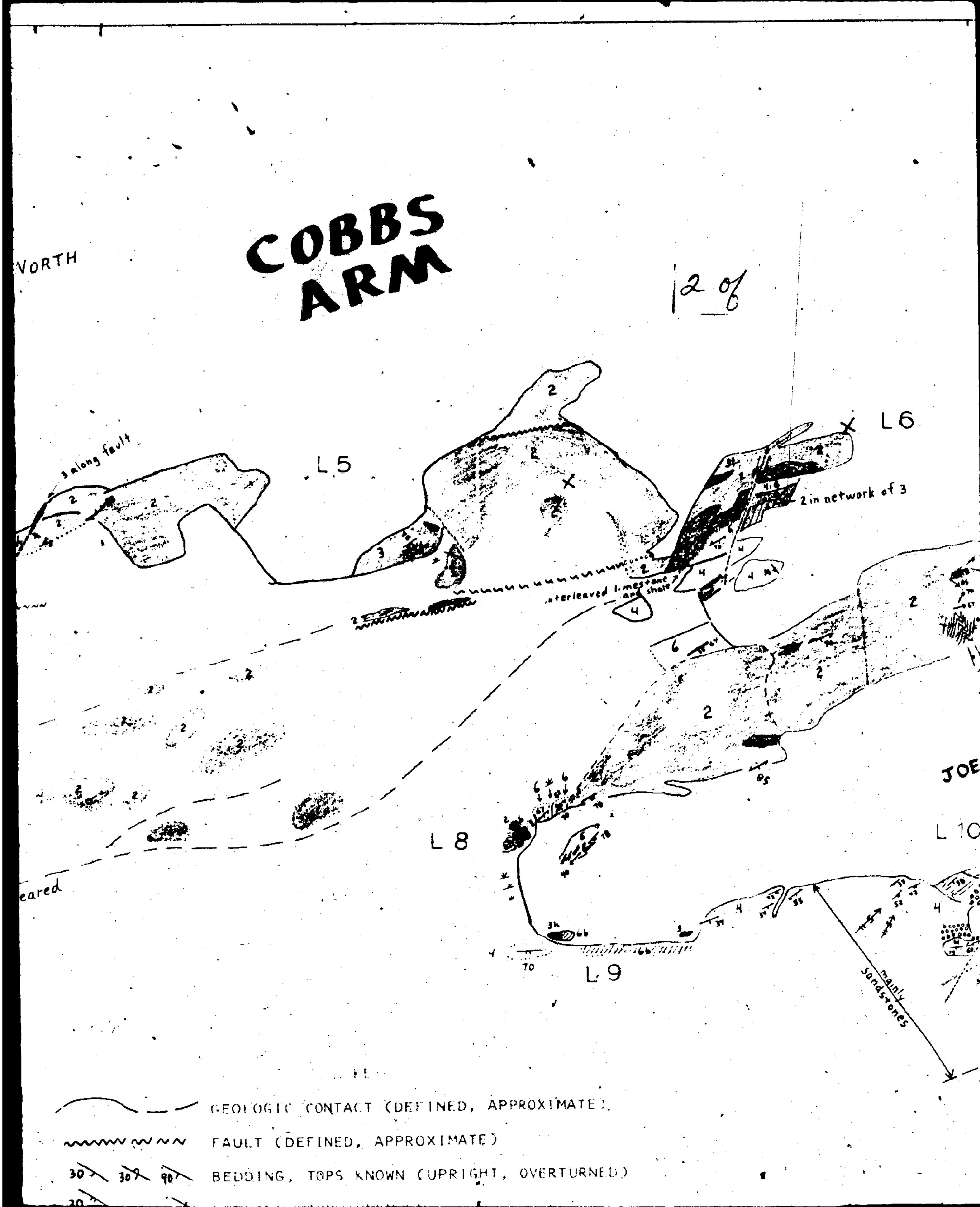
MIDDLE ORDOVICIAN (LLANDEILIAN) AND OLDER

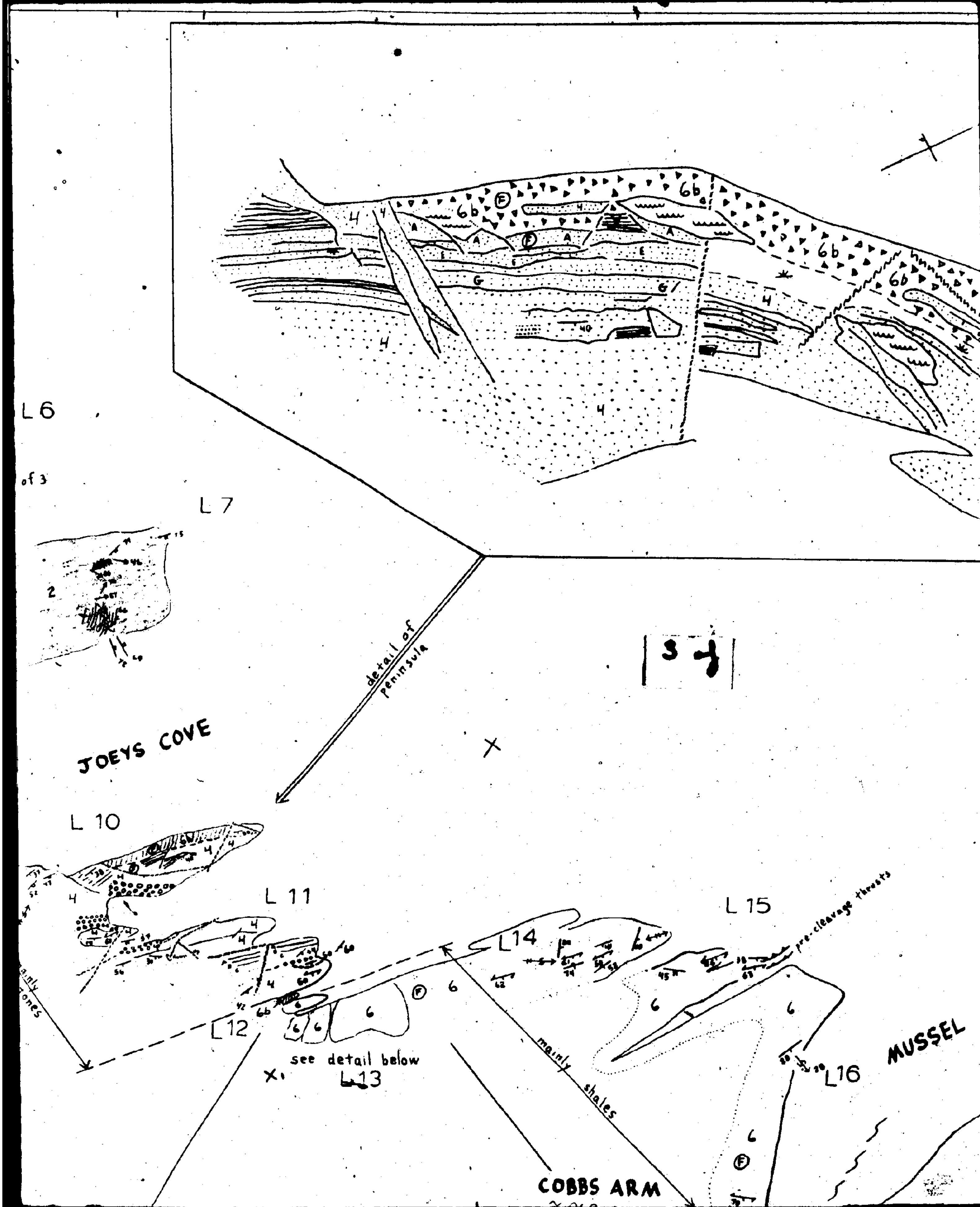
1 SQUID COVE VOLCANICS: MASSIVE BASALT

1 of

GEOLOGY BY D. REUSCH, 19[illegible]   SCALE :




COBBS ARM
NORTH
L5
L6
L8
L9
L10
JOE
s along fault
2 in network of 3
interleaved limestone and shale
mainly sandstones
eared
GEOLOGIC CONTACT (DEFINED, APPROXIMATE)
FAULT (DEFINED, APPROXIMATE)
BEDDING, TOPS KNOWN (UPRIGHT, OVERTURNED)



L 6
of 3
L 7
2
detail of peninsula
JOEYS COVE
L 10
L 11
L 12
L 13
L 14
L 15
L 16
see detail below
mainly shales
mainly ...tones
pre-cleavage thrusts
MUSSEL
COBBS ARM
6b
4
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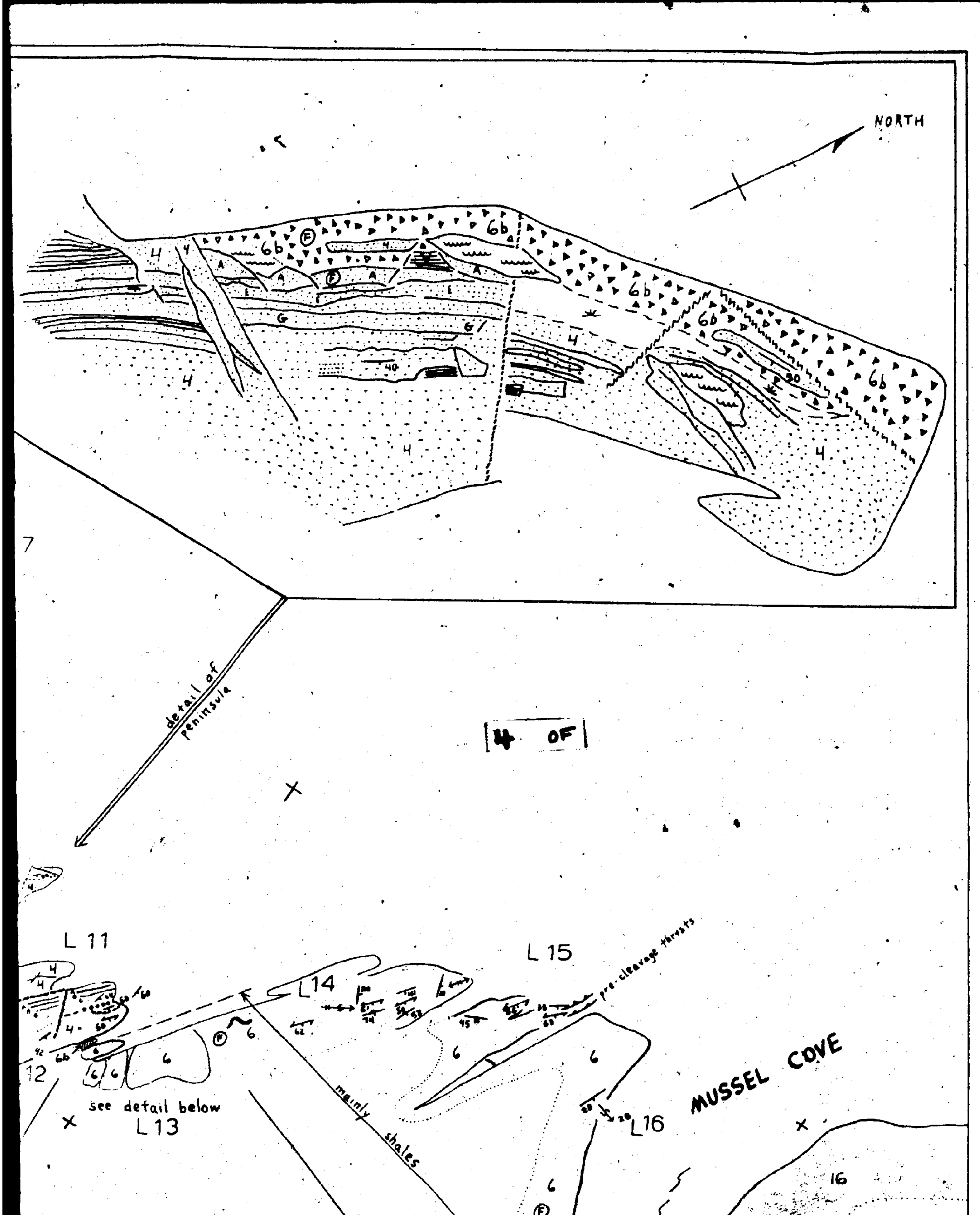
A
6



NORTH
6b
4
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G
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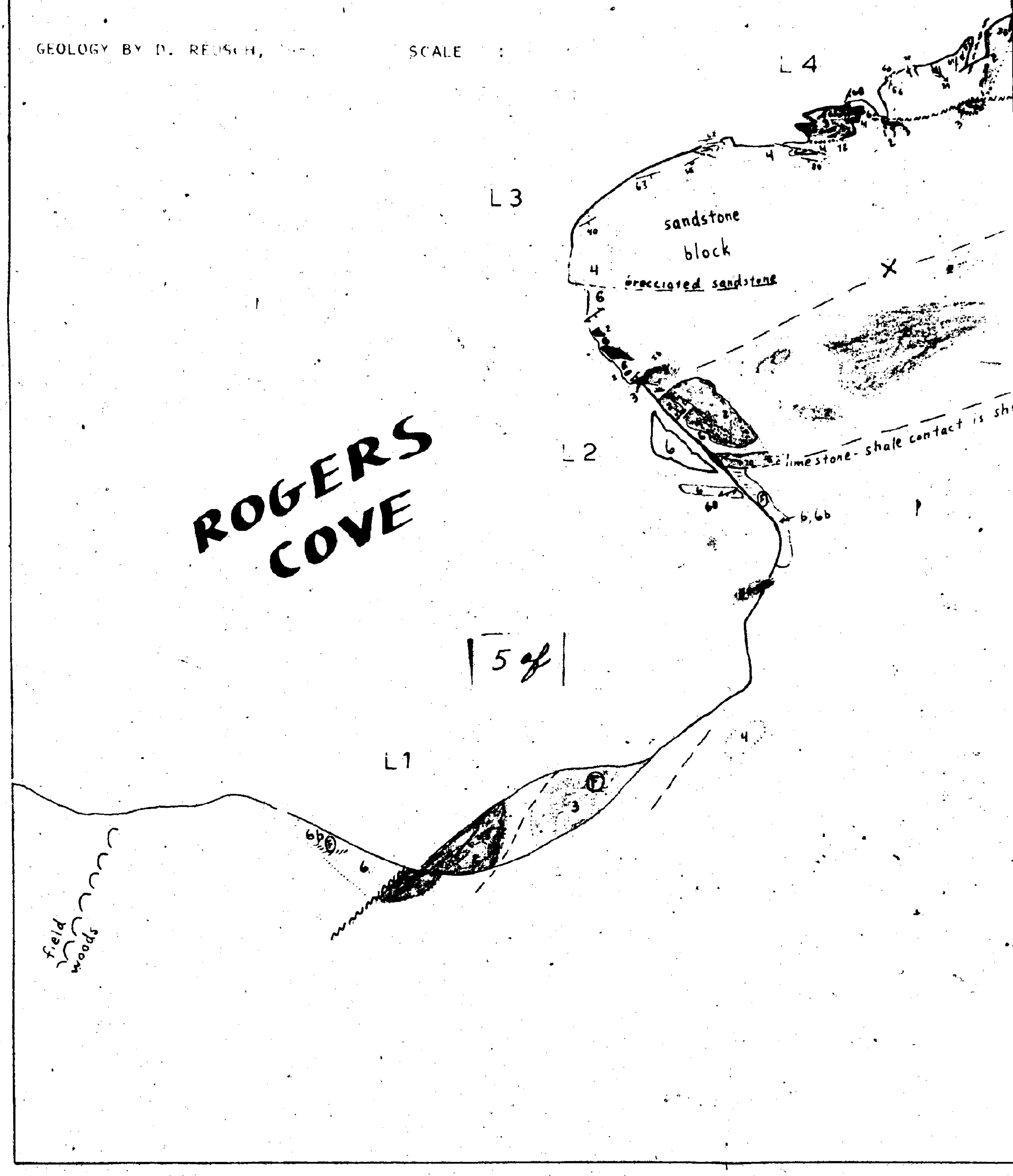
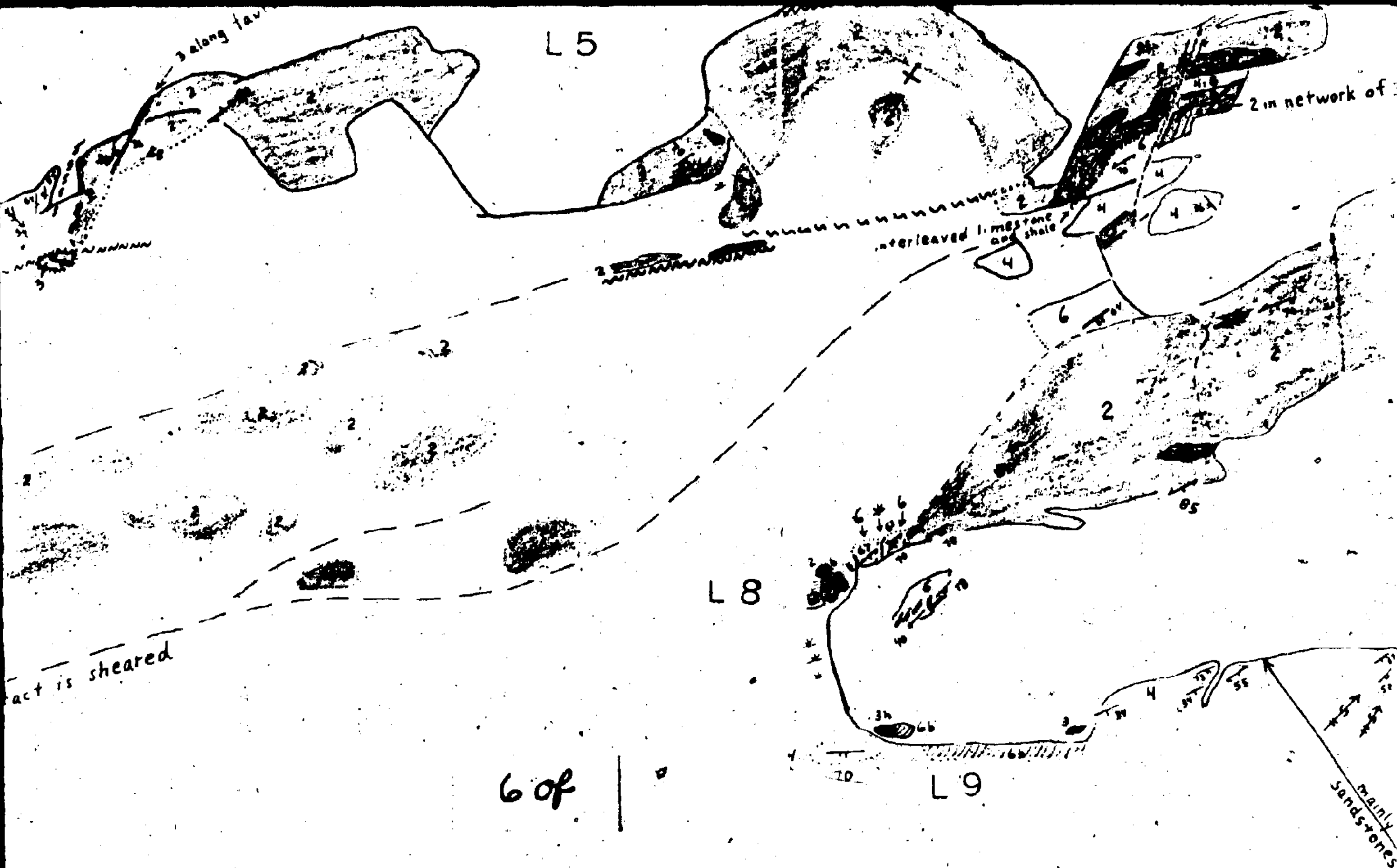
30
7
detail of peninsula
4 OF
L 11
L 15
L14
pre-cleavage thrusts
6
MUSSEL COVE
12
see detail below
L 13
mainly shales
L16
16

SQUID COVE VOLCANICS: MASSIVE BASALT

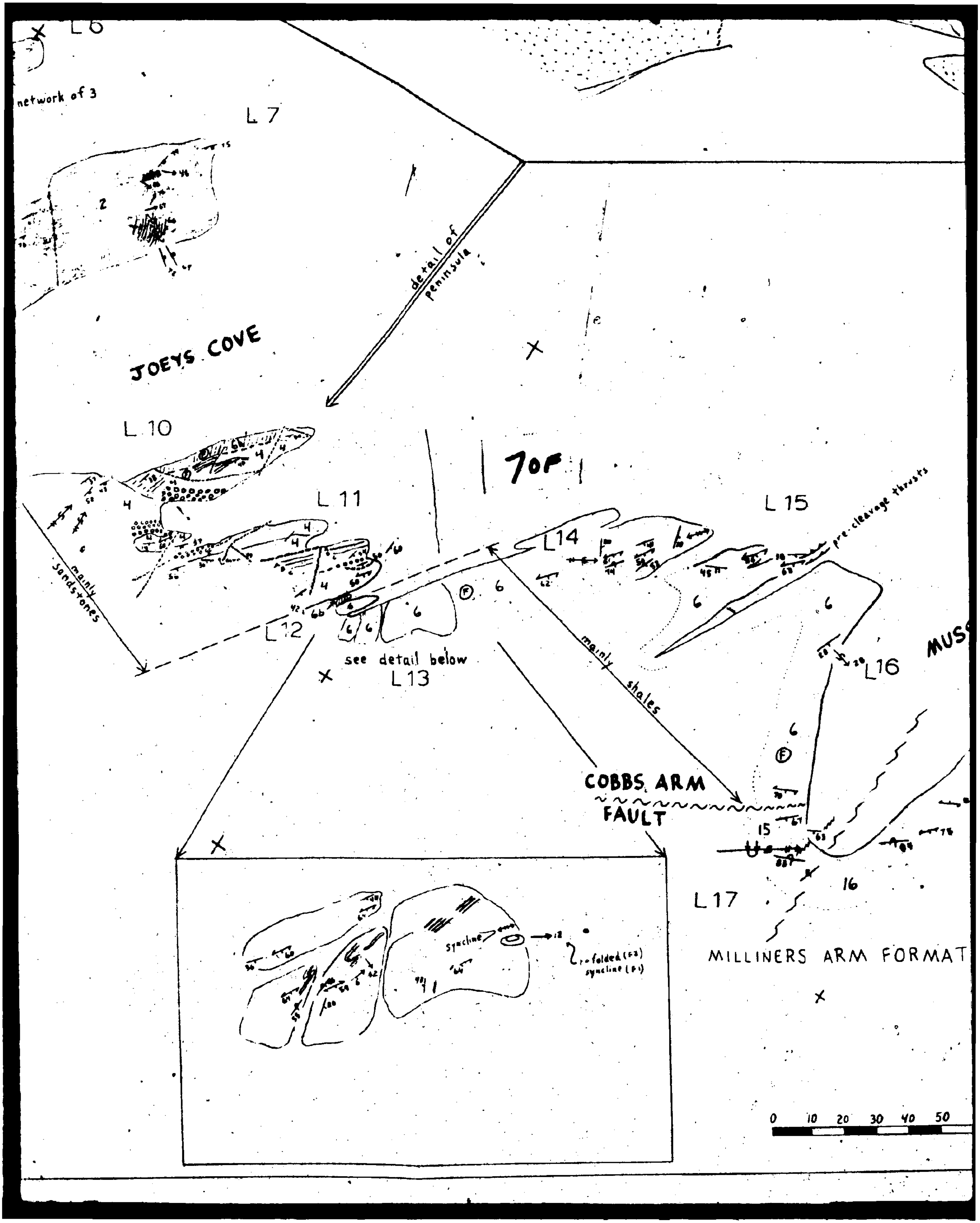
GEOLOGY BY D. REUSCH, SCALE :



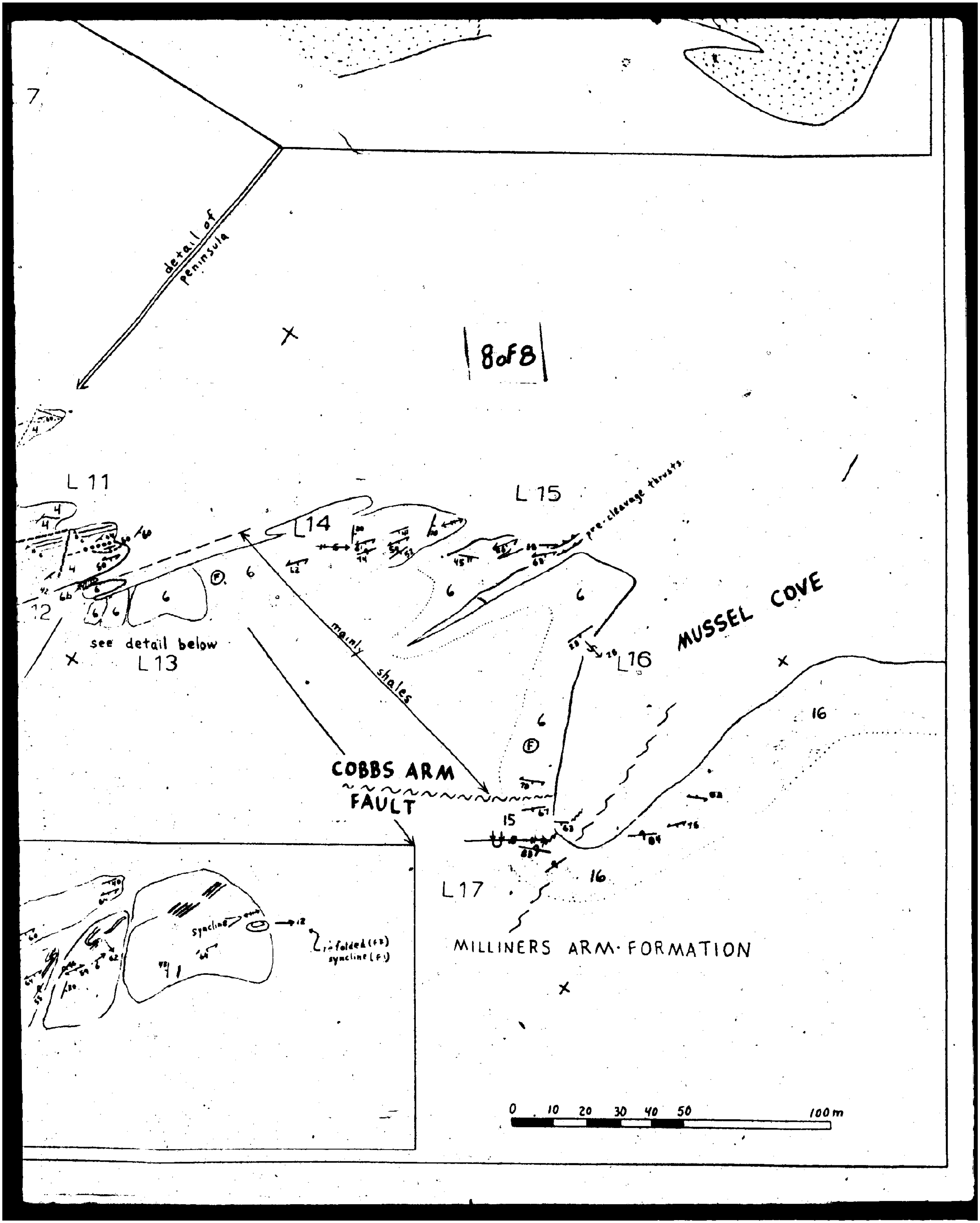


6 of

	GEOLOGIC CONTACT (DEFINED, APPROXIMATE)
	FAULT (DEFINED, APPROXIMATE)
30 30 90	BEDDING, TOPS KNOWN (UPRIGHT, OVERTURNED)
30	BEDDING, TOPS UNKNOWN
40	CLEAVAGE
30	AXIS AND ASYMMETRY OF MINOR FOLD
30	AXIAL PLANE OF MINOR FOLD
30	F FOLD
	OVERTURNED SYNCLINAL AXIS
F	FOSSIL LOCALITY
	LIMIT OF OUTCROP
	COVER (BOULDER BEACH)
L1 - L17	LOCALITIES REFERRED TO IN TEXT



L 6
network of 3
L 7
detail of peninsula
JOEYS COVE
L 10
70F
L 11
L 14
L 15
pre-cleavage thrusts
mainly sandstones
L 12
see detail below
L 13
mainly shales
L 16
MUS
COBBS ARM FAULT
L 17
MILLINERS ARM FORMAT
syncline
refolded (F2) syncline (F1)
0 10 20 30 40 50



7
detail of peninsula
8 of 8
L 11
L 15
L 14
pre-cleavage thrusts
12
see detail below
L 13
mainly shales
MUSSEL COVE
L16
16
COBBS ARM
FAULT
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L 17
MILLINERS ARM · FORMATION
syncline
refolded (F2)
syncline (F1)
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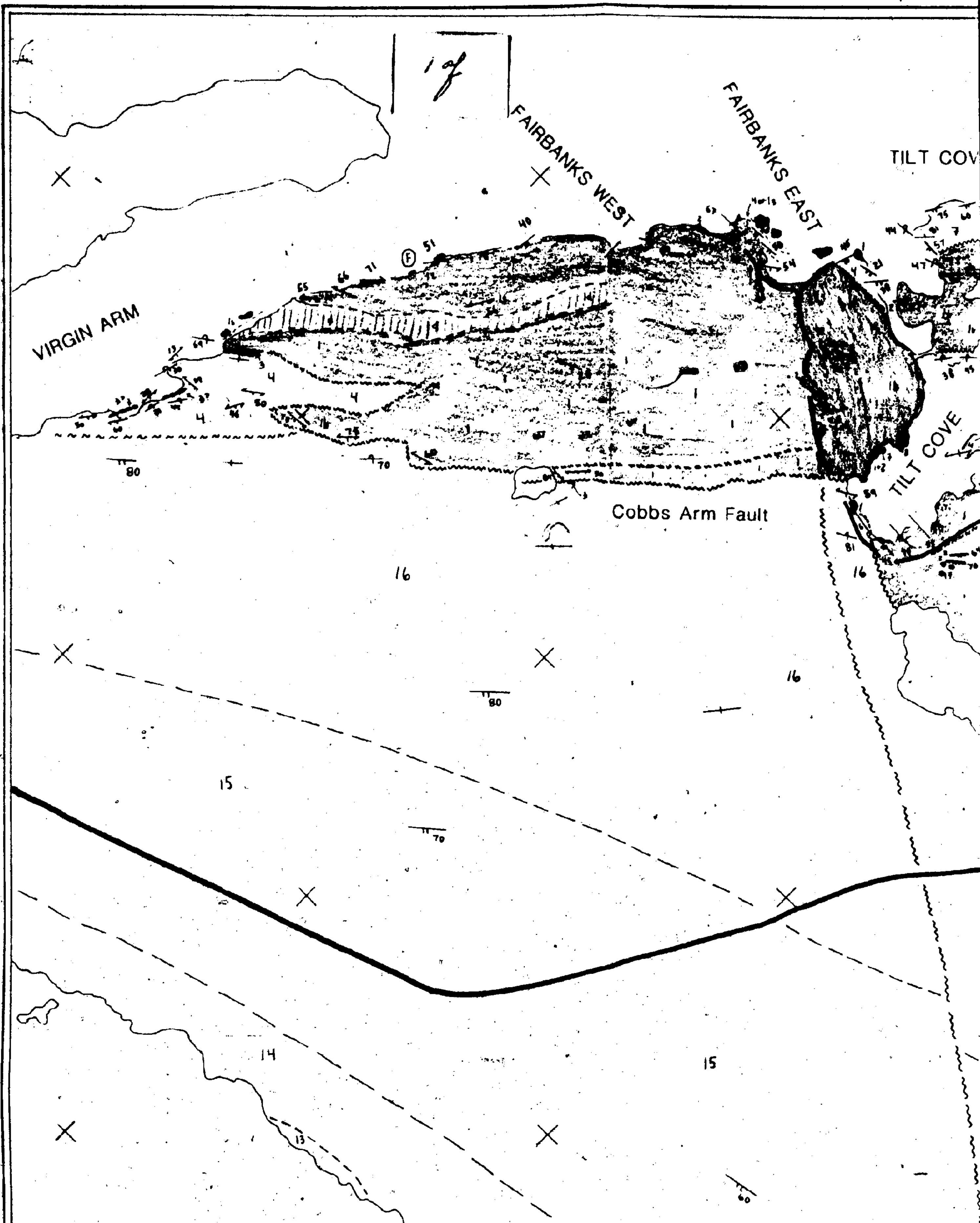

1 of
FAIRBANKS WEST
FAIRBANKS EAST
TILT COV
VIRGIN ARM
TILT COVE
Cobbs Arm Fault
16
16
16
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15
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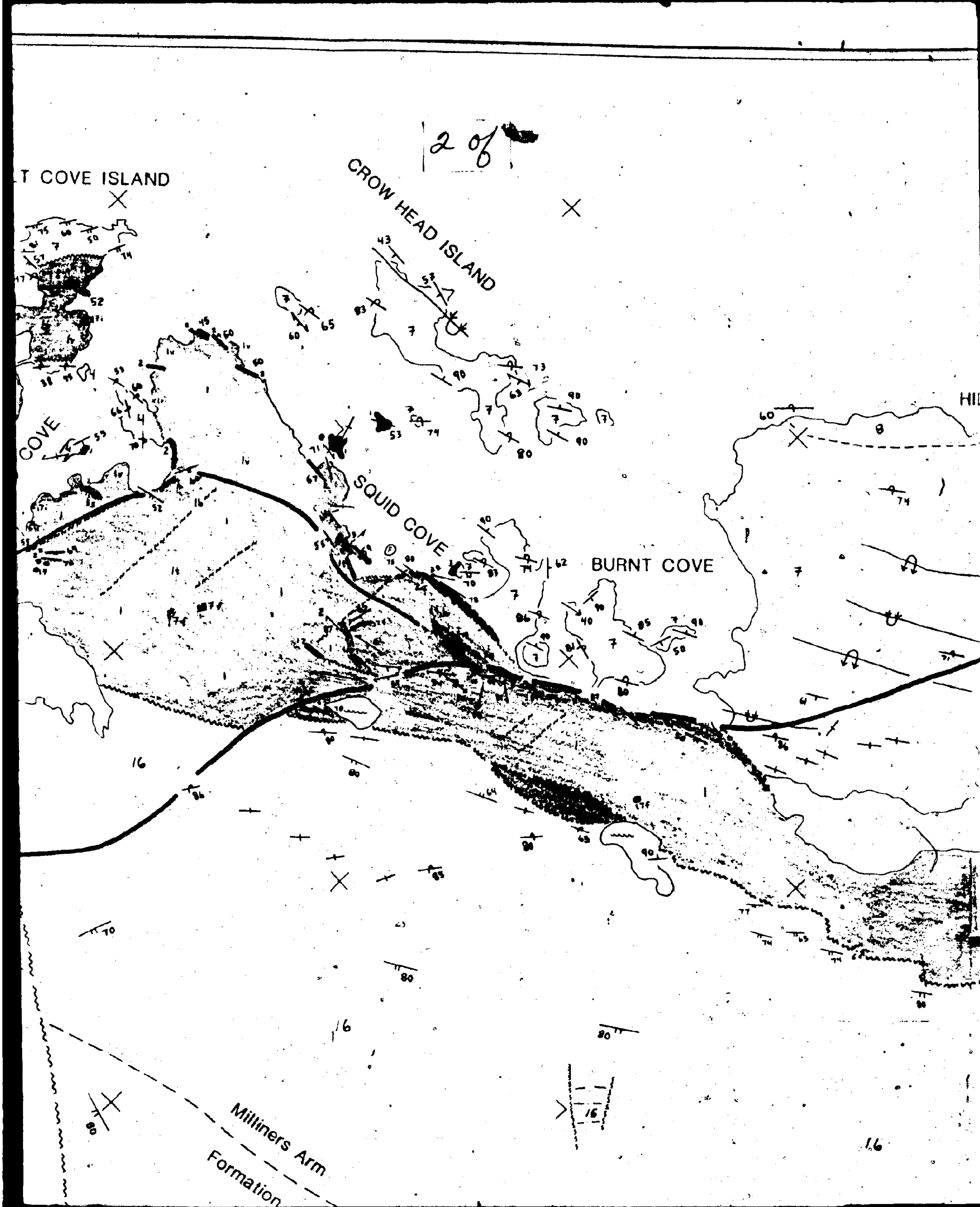
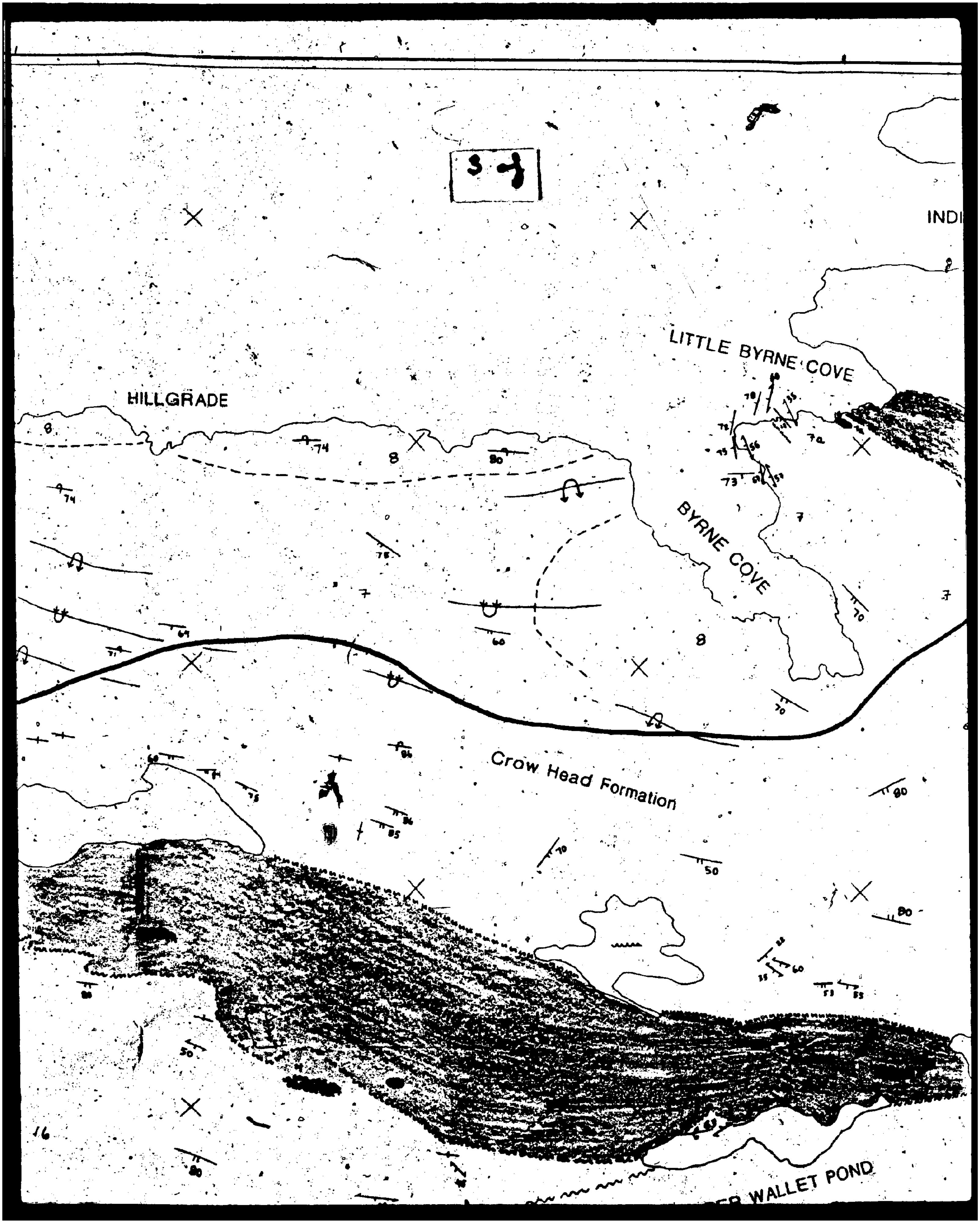
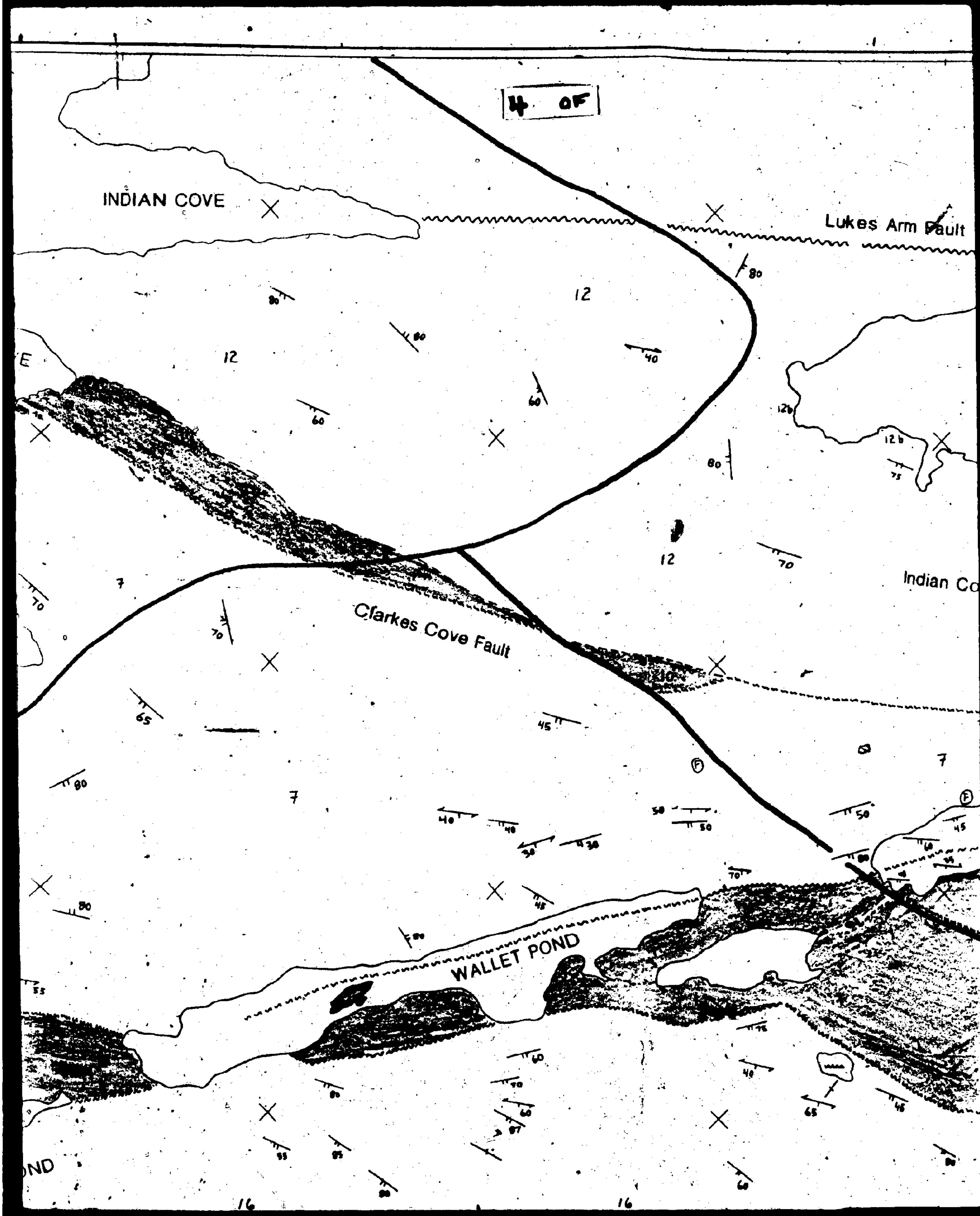

2 of
T COVE ISLAND
CROW HEAD ISLAND
COVE
SQUID COVE
BURNT COVE
HIL
Milliners Arm
Formation



3-j
INDI
LITTLE BYRNE COVE
HILLGRADE
BYRNE COVE
Crow Head Formation
WALLET POND



4 OF
INDIAN COVE
Lukes Arm Fault
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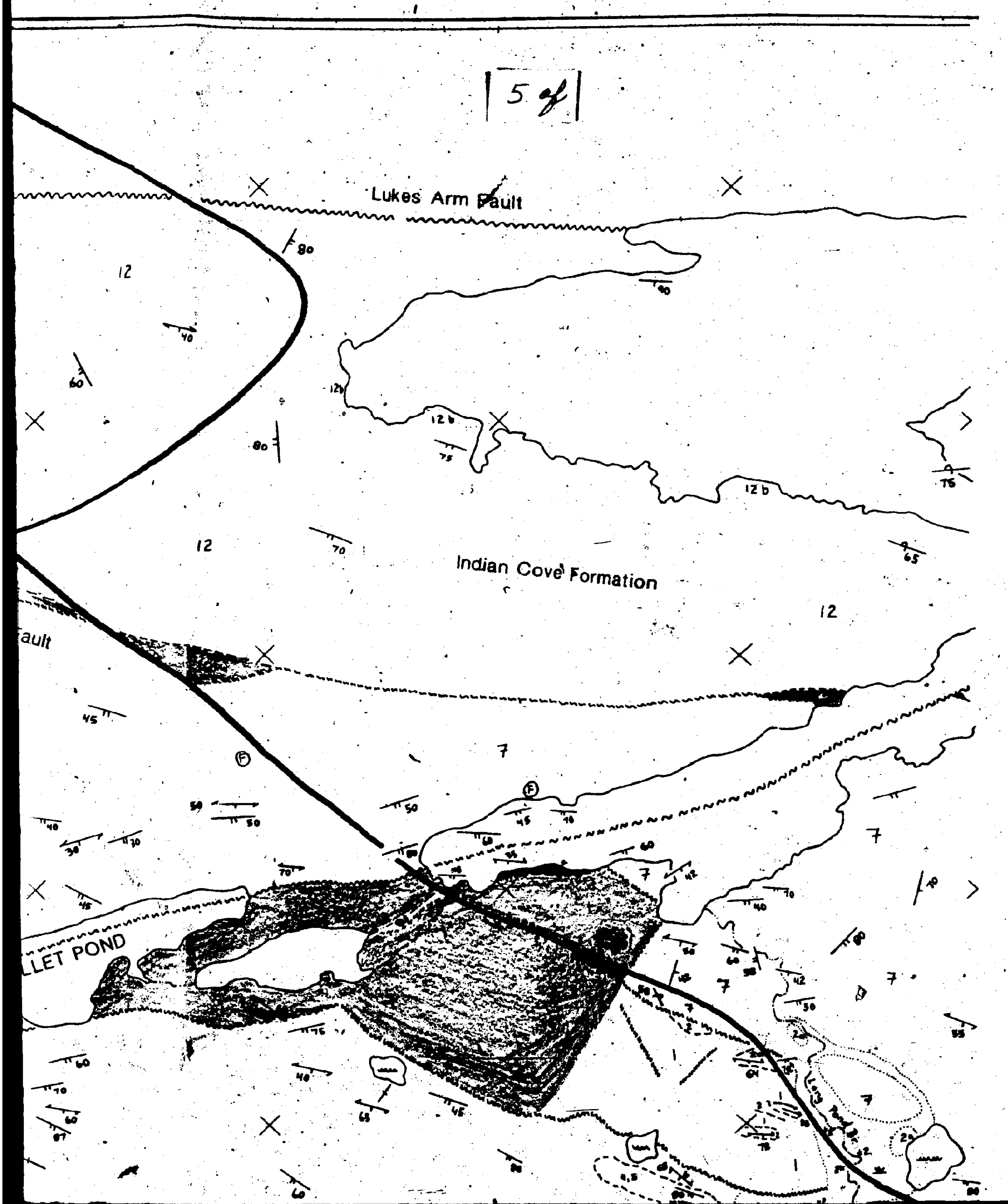
12b
12b
12
Indian Co
7
Clarkes Cove Fault
7
7
WALLET POND
OND
16
16


Lukes Arm Fault
Indian Cove Formation
12
12b
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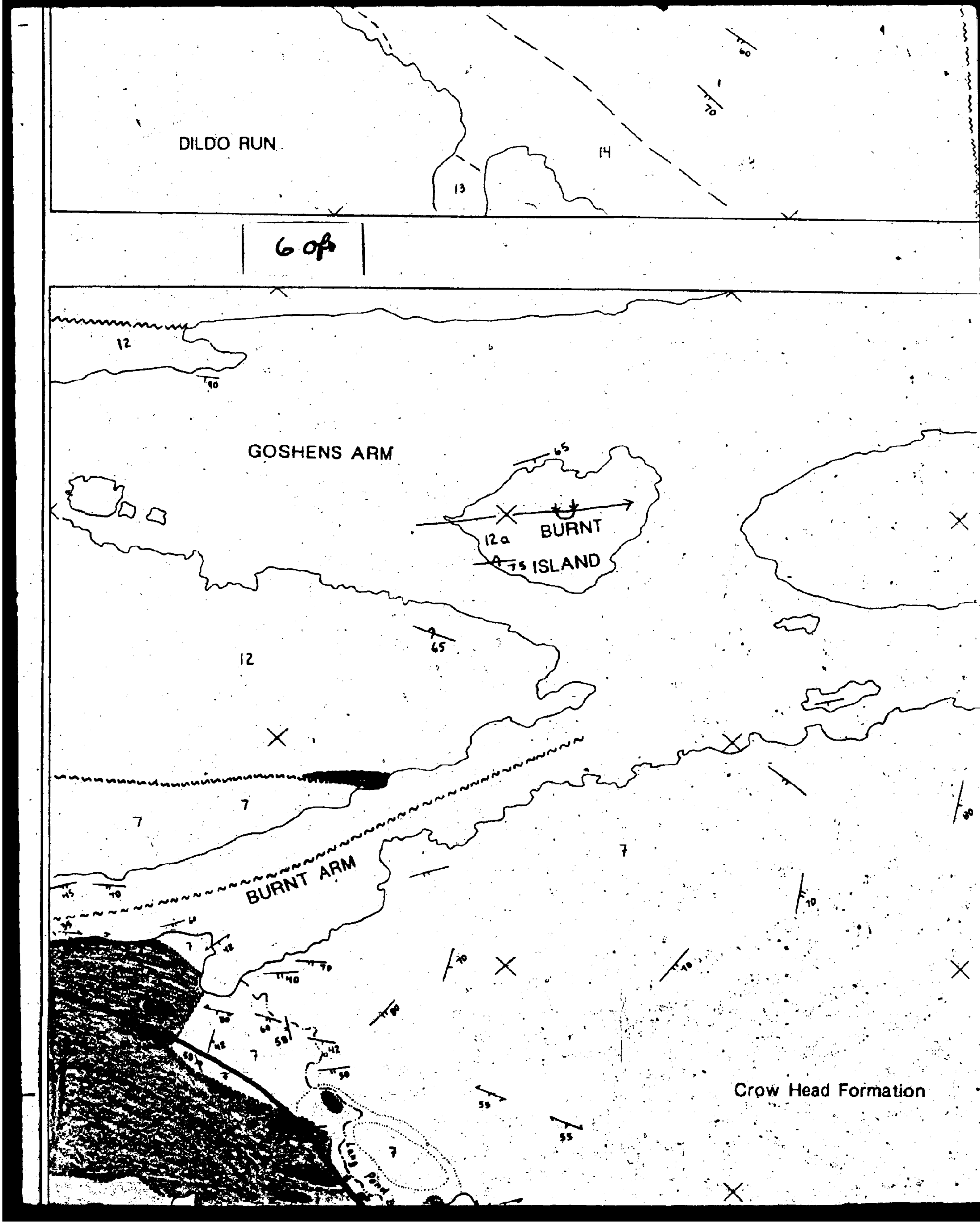
Fault
LLET POND


DILDO RUN
14
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6 of
12
GOSHENS ARM
BURNT
ISLAND
12a
12
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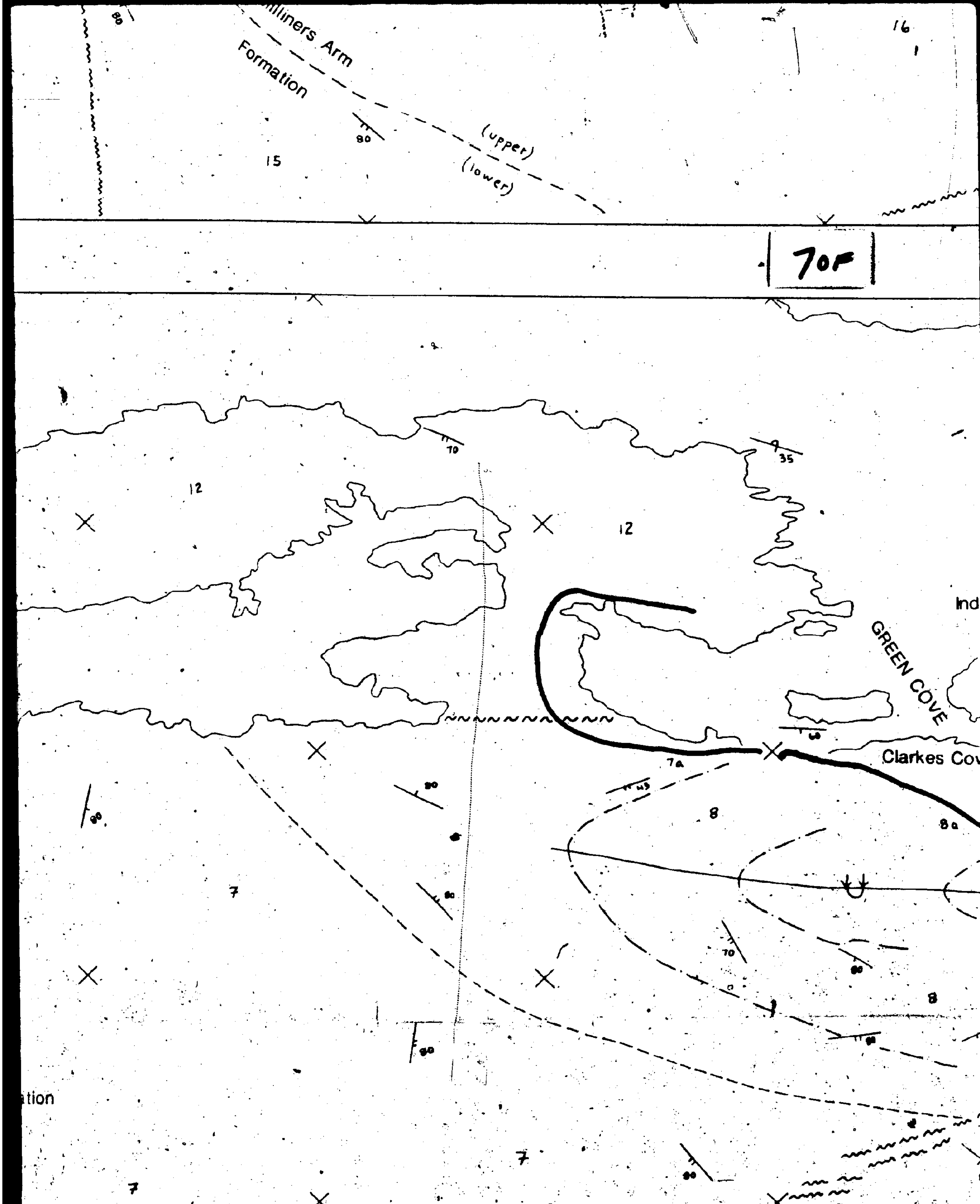
7
7
BURNT ARM
7
7
Crow Head Formation



Milliners Arm
Formation
(upper)
(lower)
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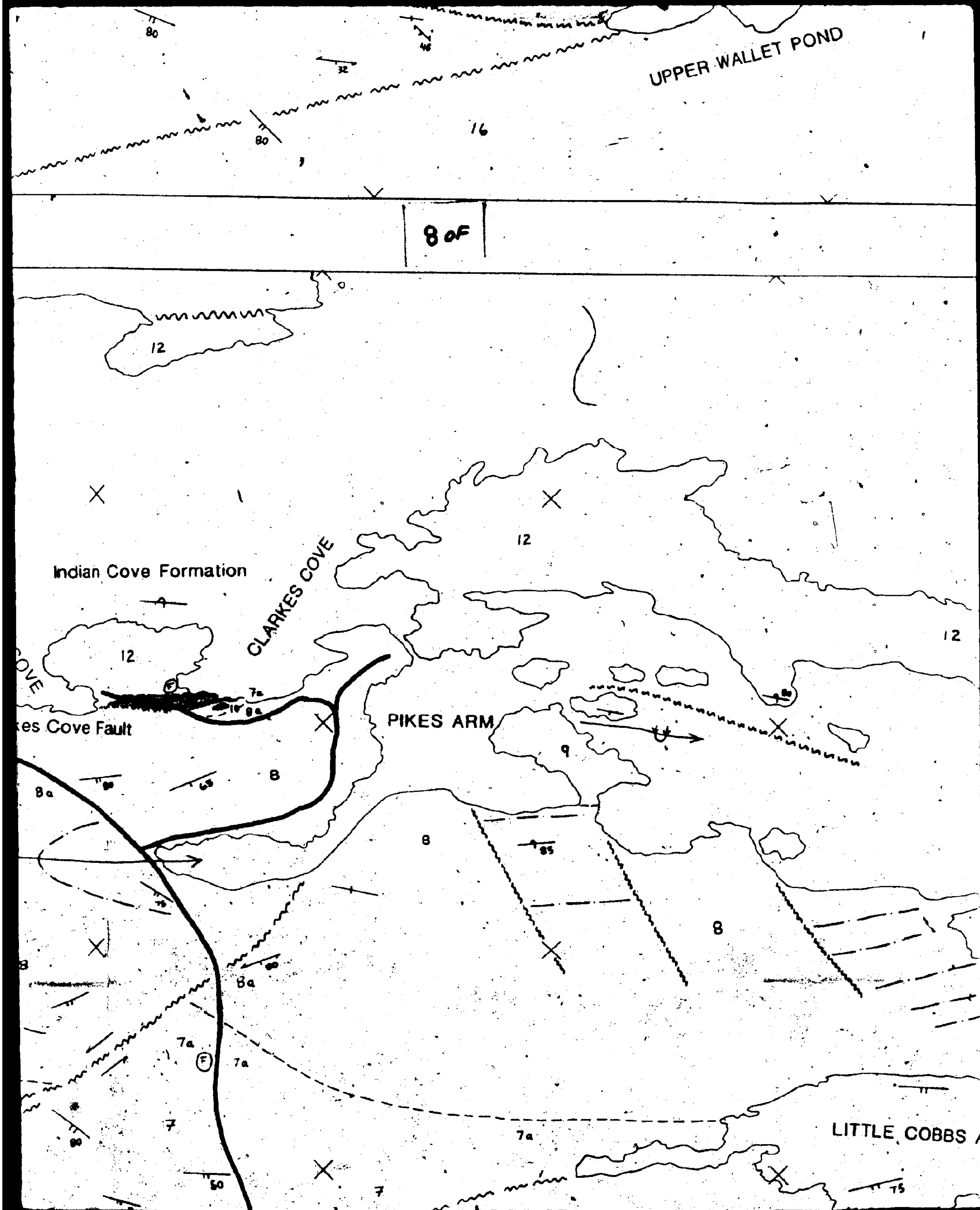

UPPER WALLET POND
16
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Indian Cove Formation
CLARKES COVE
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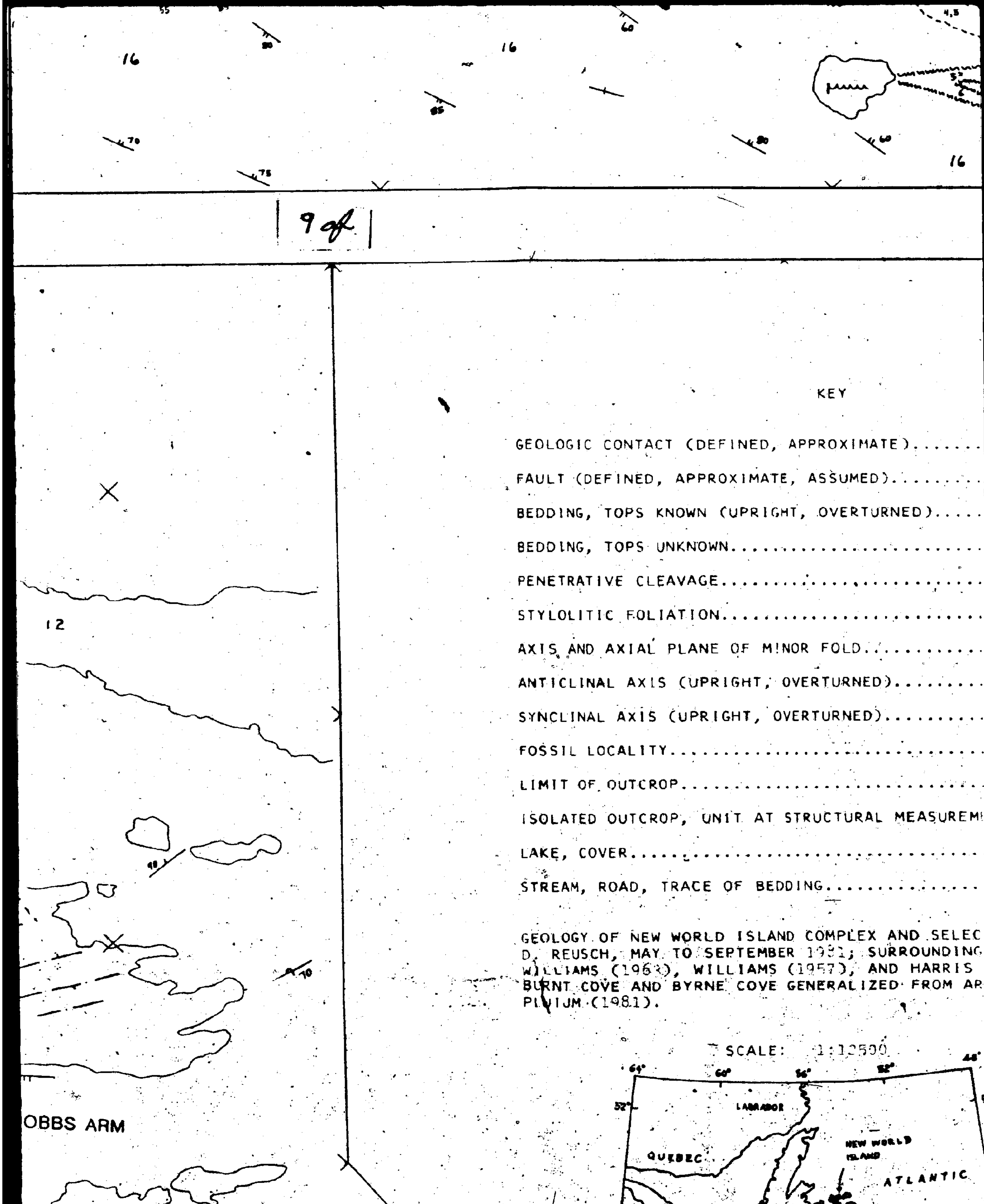
LITTLE COBBS A



9 of
16
12
KEY
GEOLOGIC CONTACT (DEFINED, APPROXIMATE).......
FAULT (DEFINED, APPROXIMATE, ASSUMED).........
BEDDING, TOPS KNOWN (UPRIGHT, OVERTURNED).....
BEDDING, TOPS UNKNOWN.........................
PENETRATIVE CLEAVAGE..........................
STYLOLITIC FOLIATION..........................
AXIS AND AXIAL PLANE OF MINOR FOLD............
ANTICLINAL AXIS (UPRIGHT, OVERTURNED).........
SYNCLINAL AXIS (UPRIGHT, OVERTURNED)..........
FOSSIL LOCALITY...............................
LIMIT OF OUTCROP..............................
ISOLATED OUTCROP, UNIT AT STRUCTURAL MEASUREM
LAKE, COVER...................................
STREAM, ROAD, TRACE OF BEDDING................
GEOLOGY OF NEW WORLD ISLAND COMPLEX AND SELEC
D. REUSCH, MAY TO SEPTEMBER 1981; SURROUNDING
WILLIAMS (1963), WILLIAMS (1957), AND HARRIS
BURNT COVE AND BYRNE COVE GENERALIZED FROM AR
PLUVIUM (1981).
SCALE: 1:12500
LABRADOR
QUEBEC
NEW WORLD ISLAND
ATLANTIC
OBBS ARM

KEY

GEOLOGIC CONTACT (DEFINED, APPROXIMATE)............

FAULT (DEFINED, APPROXIMATE, ASSUMED)............

BEDDING, TOPS KNOWN (UPRIGHT, OVERTURNED).........

BEDDING, TOPS UNKNOWN..........................

PENETRATIVE CLEAVAGE..........................

STYLOLITIC FOLIATION..........................

AXIS AND AXIAL PLANE OF MINOR FOLD...............

ANTICLINAL AXIS (UPRIGHT, OVERTURNED)............

SYNCLINAL AXIS (UPRIGHT, OVERTURNED)............

FOSSIL LOCALITY..............................

LIMIT OF OUTCROP..............................

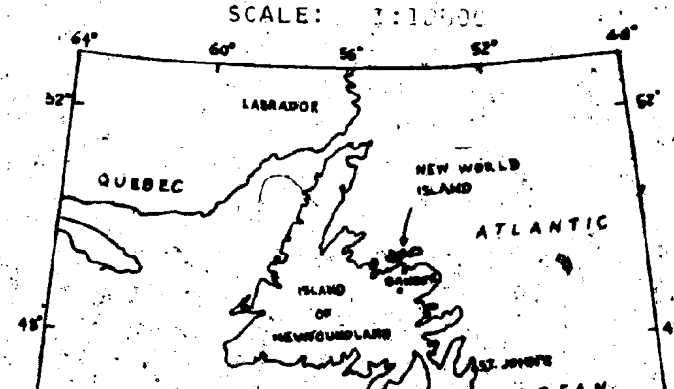
ISOLATED OUTCROP, UNIT AT STRUCTURAL MEASUREMENT...

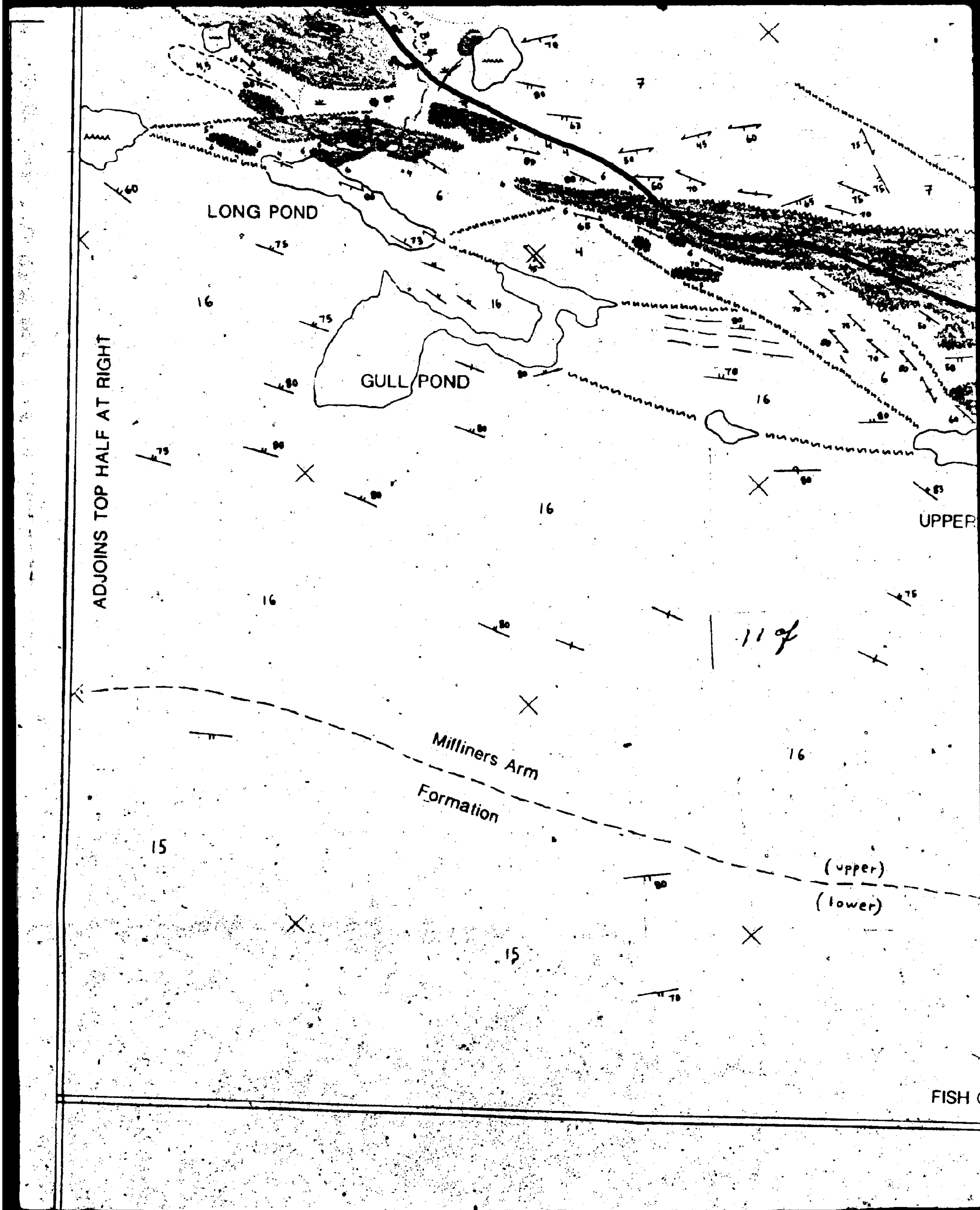
LAKE, COVER..................................

STREAM, ROAD, TRACE OF BEDDING....................

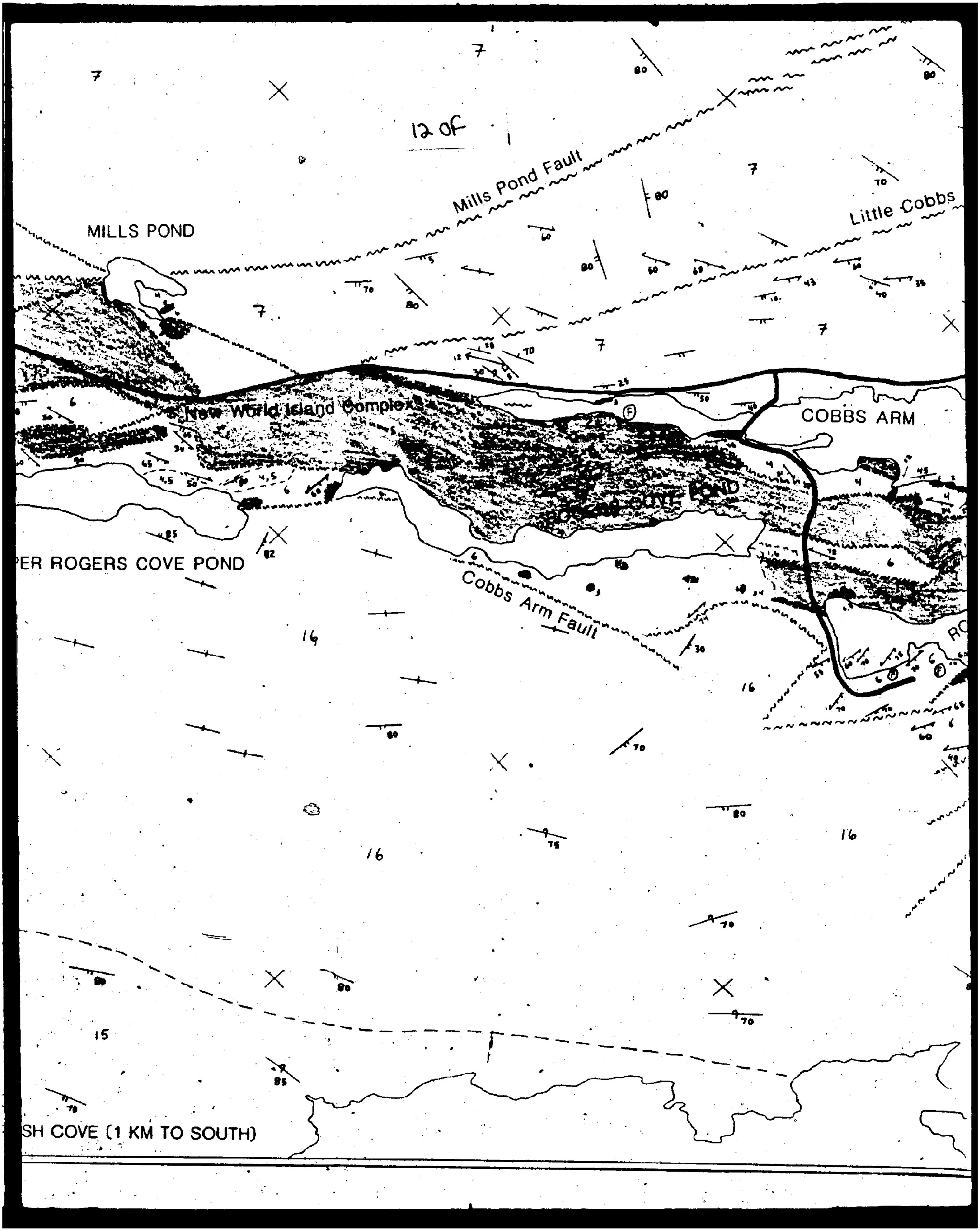
GEOLOGY OF NEW WORLD ISLAND COMPLEX AND SELECTED OTHER AREAS BY D. REUSCH, MAY TO SEPTEMBER [illegible]; SURROUNDING AREA COMPILED FROM WILLIAMS (196[illegible]), WILLIAMS ([illegible]), AND HARRIS (196[illegible]); AREA BETWEEN BURNT COVE AND BYRNE COVE GENERALIZED FROM ARNOTT AND VAN DER PLUIJM ([illegible]).

SCALE: 1:[illegible]

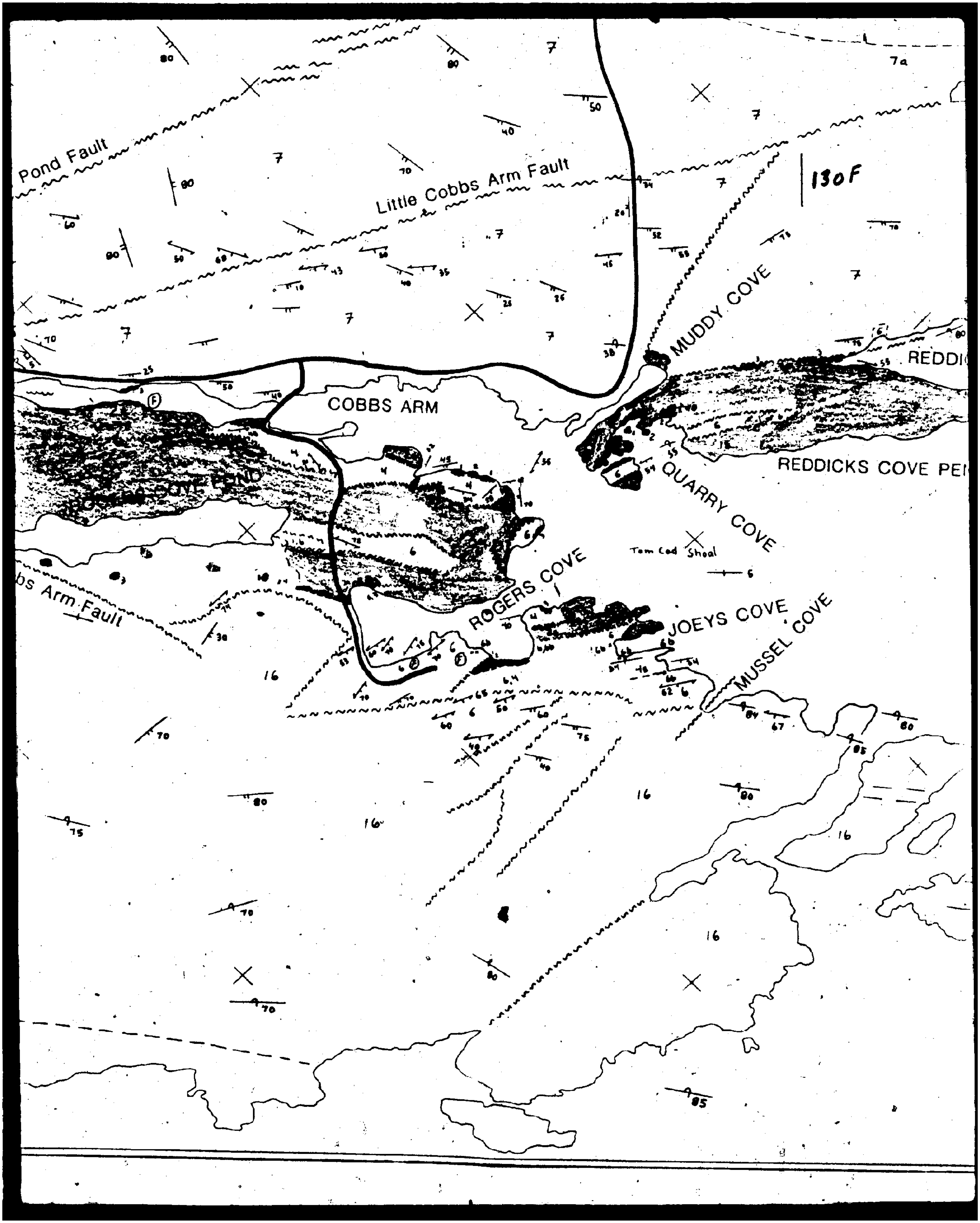




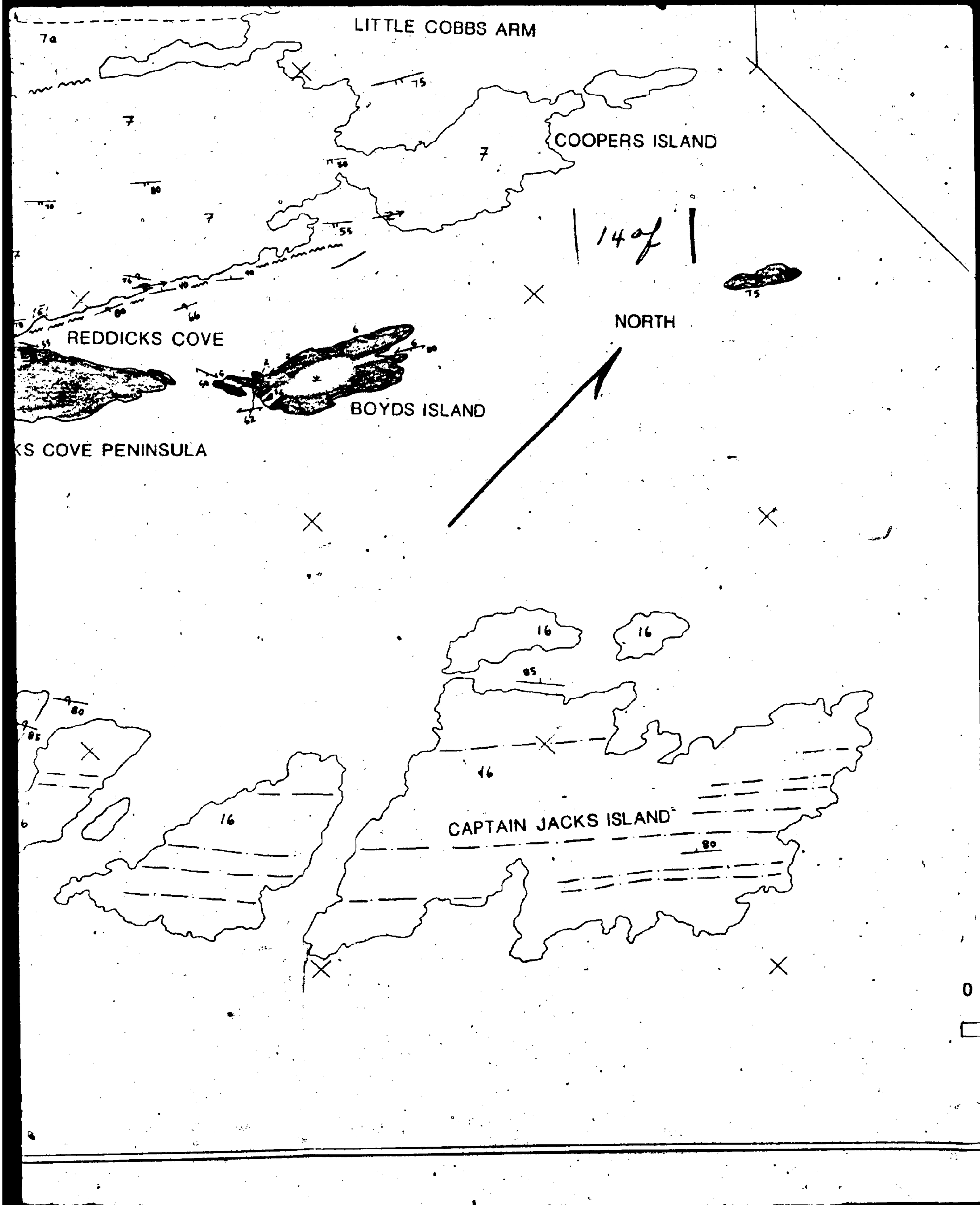
ADJOINS TOP HALF AT RIGHT
LONG POND
GULL POND
UPPER
Milliners Arm
Formation
(upper)
(lower)
FISH



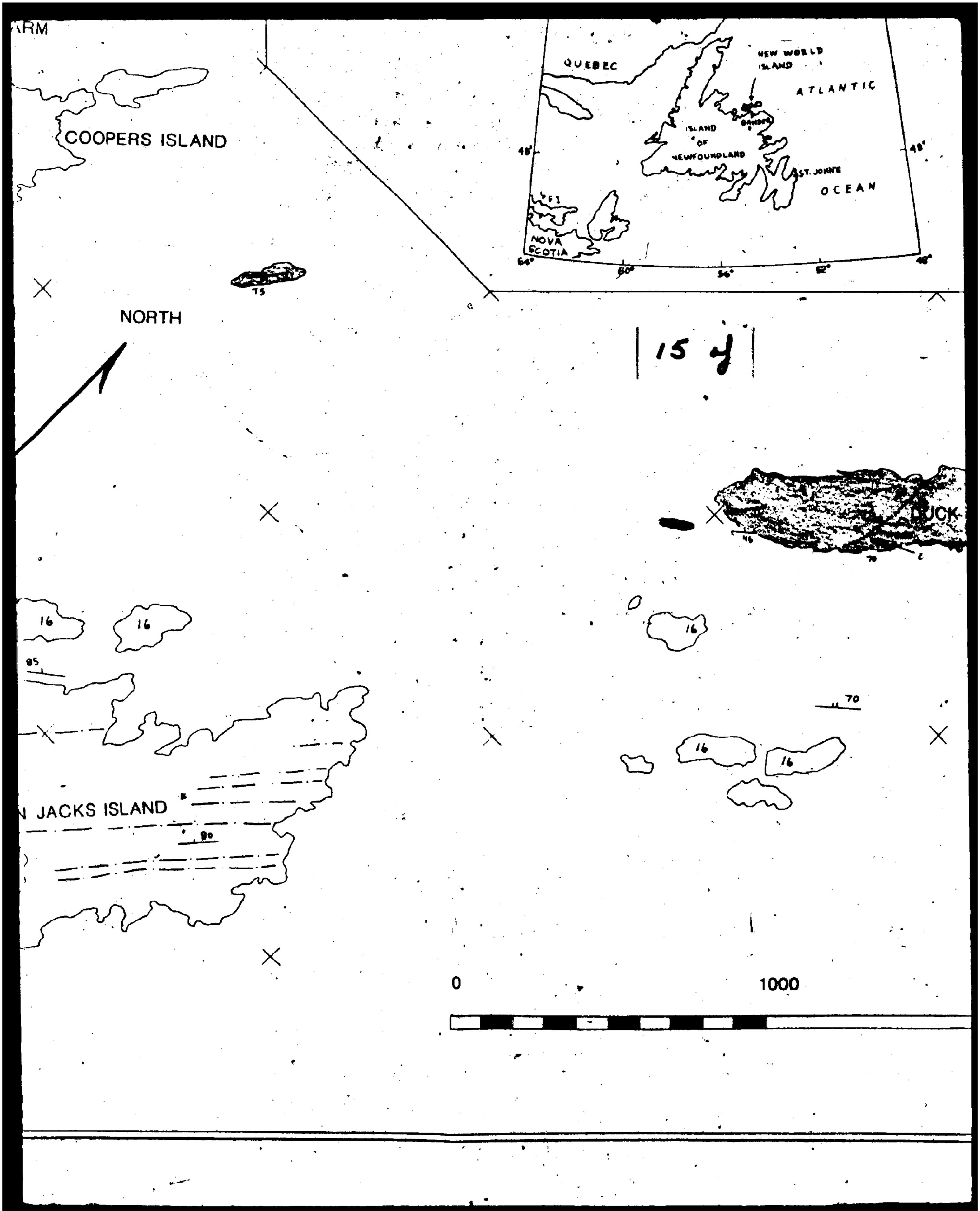
12 of
Mills Pond Fault
MILLS POND
Little Cobbs
New World Island Complex
COBBS ARM
ROGERS COVE POND
PER ROGERS COVE POND
Cobbs Arm Fault
SH COVE (1 KM TO SOUTH)



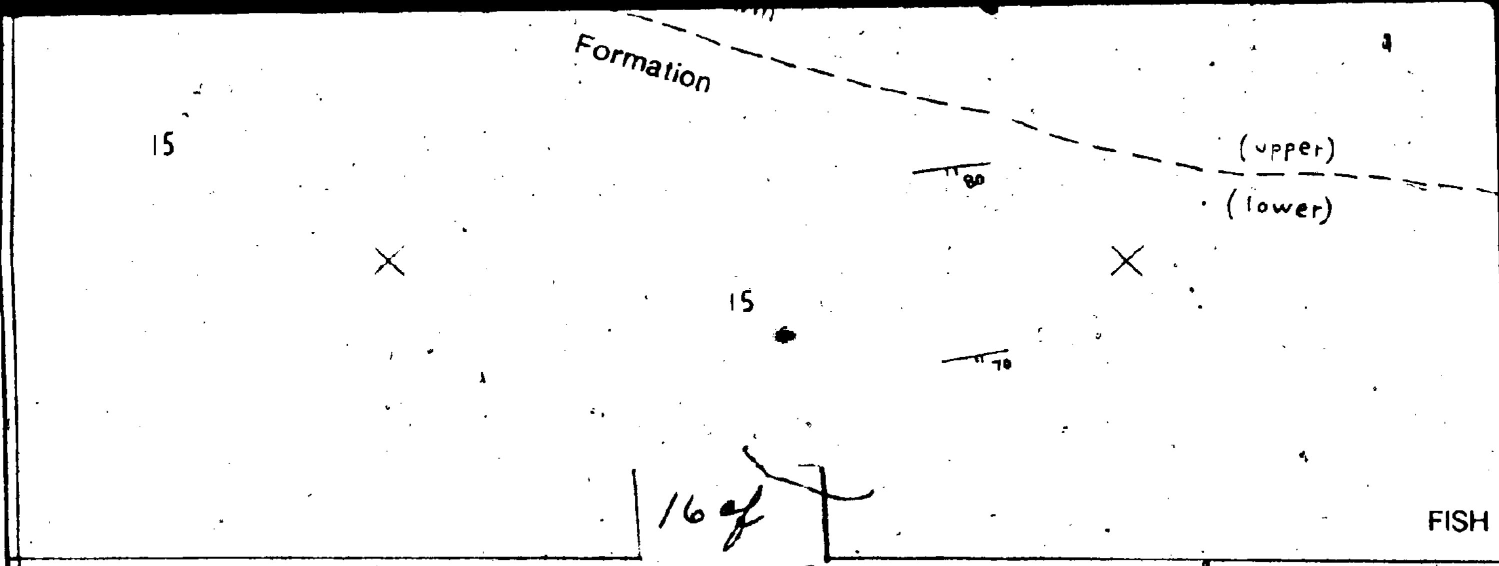
Pond Fault
Little Cobbs Arm Fault
130F
MUDDY COVE
REDDICKS COVE PEN
COBBS ARM
QUARRY COVE
Tom Cod Shoal
ROGERS COVE
JOEYS COVE
MUSSEL COVE
bs Arm Fault



LITTLE COBBS ARM
COOPERS ISLAND
14 of
NORTH
REDDICKS COVE
BOYDS ISLAND
KS COVE PENINSULA
CAPTAIN JACKS ISLAND



COOPERS ISLAND
NORTH
QUEBEC
NEW WORLD ISLAND
ATLANTIC
ISLAND OF NEWFOUNDLAND
ST. JOHNS
OCEAN
NOVA SCOTIA
15 g
JACKS ISLAND
16
16
16
16
16
85
80
70
75
0
1000



NORTHWEST

SILURIAN

12 INDIAN COVE FORMATION: COARSE RED CONGLOMERATE; A; RED SANDSTONE; B, GREY FOSSILIFEROUS SHALE

SILURIAN AND U
CROW HEAD F

9 GREY FOSSIL
QUARTZITIC S

8 GREY POLYMI
COARSE RED

7 INTERBEDDE
AND SHALE;
MEMBER)

MIDDLE ORDOVICIAN (CARADOCIAN)

RODGERS COVE SHALE: INTERBEDDED BLACK, GRAPTOLITIC SHALE AND CHERT

MIDDLE ORDOVICIAN (LLANDEILIAN) OR OLDER

CLARKES COVE VOLCANICS: GREEN BASALT AND RELATED PYROCLASTIC ROCKS, MINOR LIMESTONE

MAP 1: GEOLOGICAL MAP OF EAST

17 OF

AND UPPER ORDOVICIAN?
HEAD FORMATION (-)

FOSSILIFEROUS SHALE AND CROSS BEDDED
ZITIC SANDSTONE (PIKE ARM MEMBER)

POLYMICTIC CONGLOMERATE; A, MAINLY
RED CONGLOMERATE

BEDDED QUARTZITIC GREYWACKE, SILTSTONE,
SHALE; A, MAINLY SHALE (GREEN COVE
R)

SILURIAN OR YOUNGER
NEW WORLD ISLAND COMPLEX (-

SILURIAN AND UPPER ORDOVICIAN

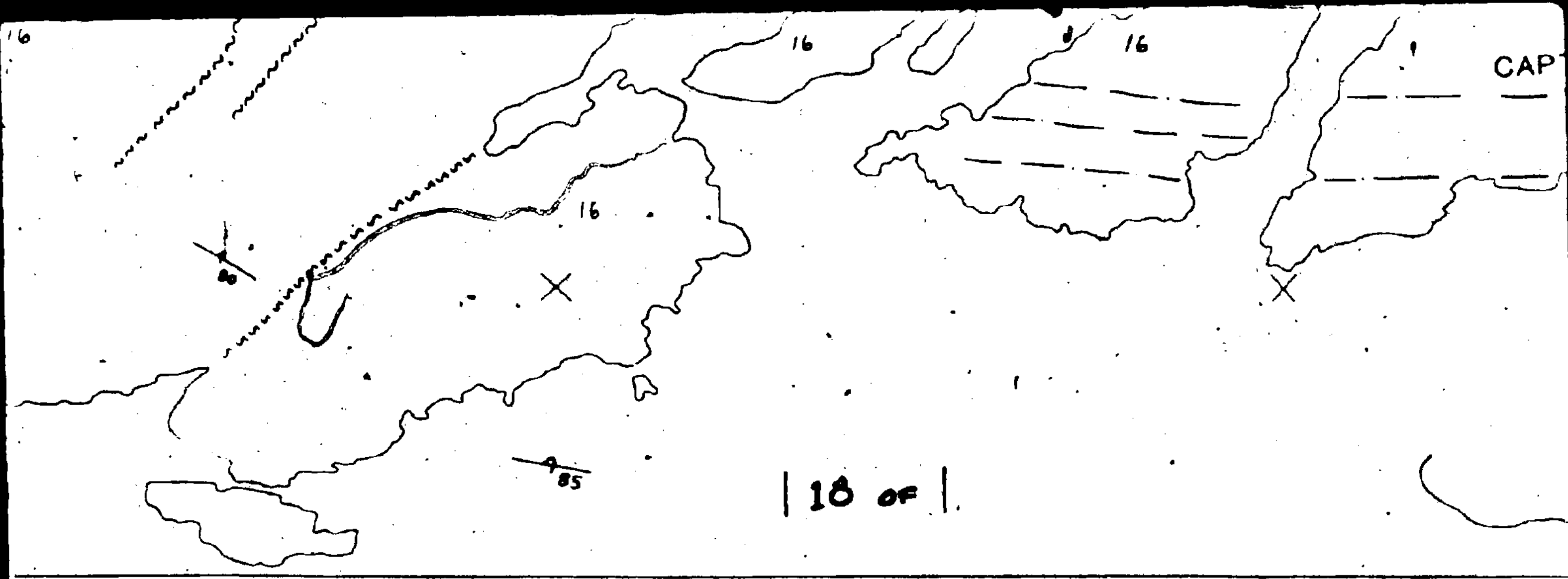
4 5 6 MUDDY COVE CLASTICS: , INTERB
AND GREY SHALE: , GREY POLYM
, MAINLY SHALE, MINOR THIN S
LOCALLY FOSSILIFEROUS; B, SH

MIDDLE ORDOVICIAN (CARADOCIAN)
RODGERS COVE SHALE: INTERBED
GRAPTOLITIC SHALE AND CHERT;
ARGILLACEOUS LIMESTONE

MIDDLE ORDOVICIAN (LLANDEILIAN)
COBBS ARM LIMESTONE: GREY,
LIMESTONE

LOWER TO MIDDLE ORDOVICIAN (AREN
SQUID COVE VOLCANICS: MAFIC LA
VOLCANICLASTIC SEDIMENTS, AN
AND RED LAVAS; B, VOLCANIC B
S, VOLCANILITHIC SANDSTONES;

ASTERN NEW WORLD ISLAND



LEGEND

SILURIAN OR YOUNGER
DIKES: F, FELSIC (QUARTZ-PHYRIC RHYOLITE); I, INTERMEDIATE

(-)

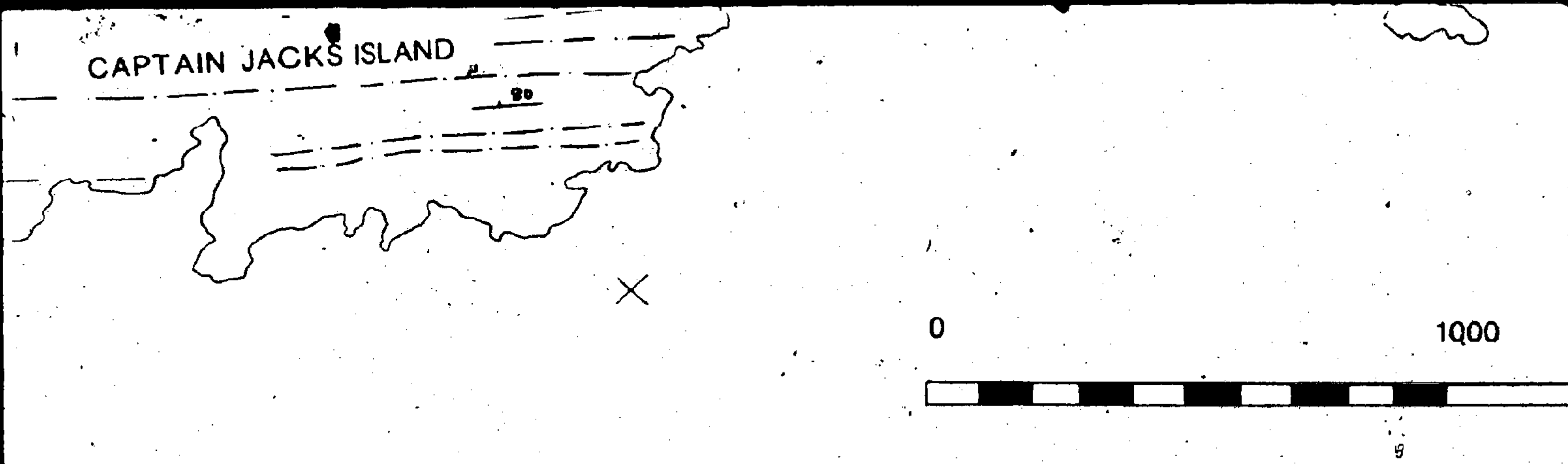
ILIAN
, INTERBEDDED QUARTZITIC GREYWACKE
EY POLYMICTIC CONGLOMERATE;
F THIN SANDSTONE INTERBEDS,
; B, SHALY CONGLOMERATIC BRECCIA

EIAN)
TERBEDDED BLACK,
CHERT; A, MINOR

ILIAN)
REY, CRYSTALLINE

MIDDLE ORDOVICIAN (LLANDEILIAN) OR OLDER
LIMESTONE, UNDIFFERENTIATED

N (ARENIGIAN TO LLANDEILIAN)
MAFIC LAVAS, PYROCLASTIC ROCKS,
TS, AND LIMESTONE; V, GREEN, GREY,
CANIC BRECCIAS; T, TUFFS;
STONES; R, RED SHALE; D, DACITE;



19 of 1

SILURIAN AND UPPER ORDOVICIAN
MILLINERS ARM FORMATION ([illegible])

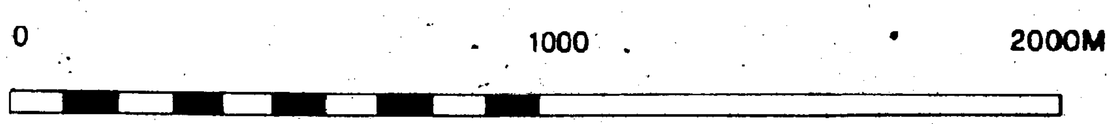
16	GREY POLYMICTIC CONGLOMERATE WITH QUARTZITIC GREYWACKE, SILTSTONE, AND SHALE INTERBEDS
15	INTERBEDDED QUARTZITIC GREYWACKE, SILTSTONE, AND SHALE

MIDDLE ORDOVICIAN (CARADOCIAN)

14	DARK HOLE SHALE: BLACK SHALE AND SILTSTONE

MIDDLE ORDOVICI
DUNNAGE MELA

13	GREEN BASALT



SOUTHEAST

ORDOVICIAN
ORMATION (

CONGLOMERATE WITH
WACKE, SILTSTONE, AND

RTZITIC GREYWACKE,
SHALE

20 OF 20

(CARADOCIAN)
: BLACK SHALE AND SILTSTONE

MIDDLE ORDOVICIAN?
DUNNAGE MELANGE

13 GREEN BASALT