Geology of eastern New World Island, Newfoundland: An accretionary terrane in the northeastern Appalachians

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ABSTRACT

Eastern New World Island is located in the northeastern part of the Dunnage Zone of the Newfoundland Appalachians. Contrary to previous interpretations, deposition of the sedimentary sequences in this area took place in a single basin, although styles of deposition varied laterally within this basin. Four generations of deformation have affected these rocks. D_1 deformation was progressive and highly heterogeneous, and it is associated with thrusting. Movement zones are present at the bases of thrusts, locally with zone-parallel cleavage (S_1). These zones show a complex deformation history. Folds overprinted by cleavage, folds with axial plane cleavage, and folded cleavages all occur. Movement zones are locally associated with tectonically deformed olistostromes. Repetition of the general stratigraphic sequence occurs as a consequence of D_1 thrusting. The thrusting direction on eastern New World Island, however, cannot be unequivocally determined.

Superimposed on D_1 deformation, there is regional folding (F_2), with a well-developed regional S_2 axial plane cleavage. Two types of F_3 folds are present, and these are associated with strike-slip faulting. F_4 deformation caused the formation of minor kinks. D_1 deformation is Lower Silurian and younger in age and is included in the Acadian orogeny of the Appalachians. Evidence for earlier, Taconic, deformation is absent.

The over-all geometry of eastern New World Island is that of a steeply dipping thrust pile with a complex internal geometry. It strongly resembles parts of the imbricate fan complex of the Southern Uplands of Scotland.

INTRODUCTION

For the past 25 yr, eastern New World Island of the Newfoundland Appalachians has been the focus of many geological studies (for example, H. Williams, 1963; Kay, 1967, 1976; McKerrow and Cocks, 1978; Watson, 1981; Karlstrom and others, 1982; Arnott, 1983a, 1983b; Reusch, 1983; van der Pluijm, 1984a). The island (Fig. 1) is located in the northeastern part of what has been called the "Central Paleozoic Mobile Belt" (H. Williams, 1964a) or "Central Volcanic Belt" (Kay, 1967). This area is now generally referred to as the "Dunnage Zone" (H. Williams, 1979) or "Dunnage Terrane" (H. Williams and Hatcher, 1982, 1983). According to H. Williams (1979) and H. Williams and Hatcher (1983), the Dunnage Zone represents vestiges of a lower Paleozoic oceanic domain where dominantly mafic volcanics and associated marine sediments locally overlie an ophiolite suite.

Eastern New World Island (Fig. 2) consists of approximately parallel belts of Ordovician and Lower Silurian rocks which, from bottom to top, consist of mafic volcanics, limestones, black shales, turbiditic graywackes, conglomerates, and mélanges[1] (McKerrow and Cocks, 1978). A somewhat confusing stratigraphic nomenclature for this area has emerged over the years. Reviews of stratigraphic relations in the Notre Dame Bay area are given by Dean (1978) and Arnott and others (1985).

H. Williams (1963) was the first to produce a detailed map and description of the eastern New World Island area (Twillingate sheet, 2E/10). He recognized repetition of the stratigraphic sequence, which he interpreted as being a result of northwest-directed thrusting (Kay and H. Williams, 1963). Kay (1967) later rejected the thrust interpretation and suggested that deformation occurred along transcurrent faults. Harris (1966) recognized a large recumbent fold that had been overprinted by strike-slip faulting in the area around Cobbs Arm (Fig. 2). In the same region, Jacobi and Schweickert (1976) identified a Silurian mélange, which they thought was associated with Silurian thrusting, an interpretation accepted by Dean and Strong (1977). A different interpretation was offered by McKerrow and Cocks (1978), who proposed that the area was largely a north-younging homoclinal sequence of trench sediments, an interpretation that was subsequently extended to the southwest by McKerrow and Cocks (1981). Arnott (1983a) suggested that deposition took place in three separate basins bounded by active faults (see also Arnott and others, 1985).

In this paper, new as well as existing stratigraphic and sedimentological data are combined with information on the timing and sequence of deformation to reconstruct the early and middle Paleozoic history of this part of the northern Appalachians.

STRATIGRAPHIC RELATIONS

The stratigraphy of eastern New World Island has been described by H. Williams (1963), Kay (1967, 1969, 1976), McKerrow and Cocks (1978), Watson (1981), Arnott (1983a), and Arnott and others (1985). Kay (1967, 1969) divided the area into three sequences, each with a distinct stratigraphy, and each separated by transcurrent faults (Fig. 3). From north to south, these are the Toogood, Cobbs Arm, and Dildo sequences. McKerrow and Cocks (1978), on the other hand, considered the area to be a single homoclinal sequence with a thick olistostromal unit in the central part (Fig. 3). Arnott (1983a) subsequently suggested that,

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[1]The term "mélange" is used here as a *non-genetic* term for chaotic units composed of blocks in a generally fine-grained matrix.

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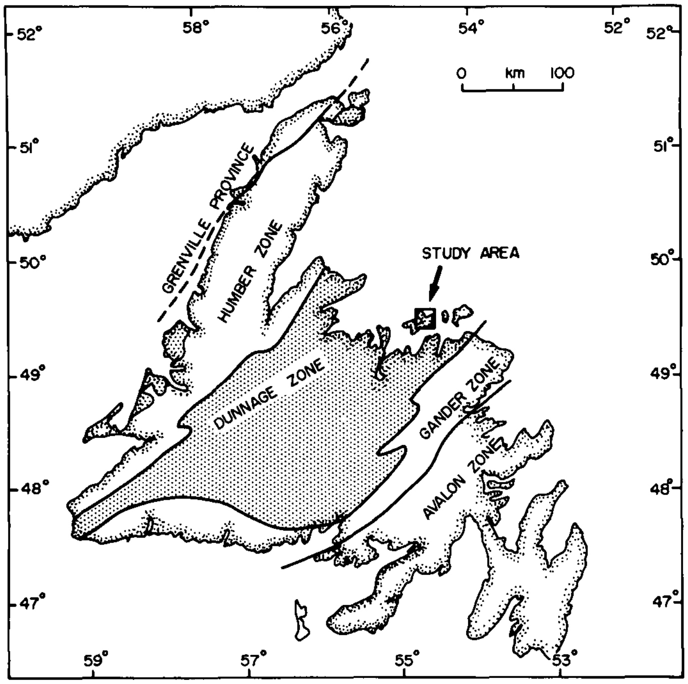


Figure 1. Zonal subdivision of Newfoundland; adapted from Williams (1979) and Kean and others (1981). Note the location of eastern New World Island.

although a thin olistostromal unit does overlie conglomerates, three stratigraphic sequences, bounded by high-angle faults, were deposited in separate basins (Fig. 3).

The major stratigraphic relations on eastern New World Island proposed herein are as follows. (1) All units were deposited in one sedimentary basin, but the resultant stratigraphic sequence is now repeated by thrust faults. (2) Lateral variations in lithology within this sequence reflect lateral variations in depositional systems in this single sedimentary basin. (3) A number of unconformities within this stratigraphic sequence (see, for example, Kay, 1969; Karlstrom and others, 1983a) result in locally condensed sections (see also Arnott, 1983a). (4) Rocks of the Dunnage Mélange (not shown in the last column of Fig. 3) are separated from overlying rocks by a thrust fault. This mélange may represent deformed, but locally older, facies equivalents of units now exposed on the island.

The oldest rocks recognized on eastern New World Island are mafic volcanics with associated tuffaceous limestones and sandstones. Pillow breccias and agglomerates locally occur at the top of this sequence. Horne and Helwig (1969) and Horne (1970) included these units in the Summerford Group which is Lower to Middle Ordovician in age (Dean, 1973; Neuman, 1976). Trace-element and REE geochemical data indicated that the mafic volcanics are mid-ocean–ridge or ocean-island basalts, and not of island-arc affinity (Jacobi and Wasowski, 1985). Llandeilian age fossiliferous limestone conformably overlies these basalts (Bergstrom and others, 1974; McKerrow and Cocks, 1978; Fahraeus and Hunter, 1981). Locally, this limestone is unconformably overlain by black shale (with minor dark chert and black pebbly mudstone) which yields Upper Llandeilo to Lower Ashgill age graptolites (Bergstrom and others, 1974; Arnott, 1983a). Dean (1978) and Kean and others (1981) recognized that this shale is a significant marker horizon that is traceable throughout the Notre Dame Bay area. At some localities (for example, Cobbs Arm area, Fig. 2), limestone blocks, probably representing slide debris, are present in the black shale. The depositional environment for this shale unit is thought to have been either a starved-restricted or large ocean basin (Watson, 1981).

Black shales are overlain by an upward-coarsening turbiditic graywacke and conglomerate sequence. The base of the sequence consists of thin-bedded, dark turbidites that grade from the Caradocian black shale into overlying light turbidites (Horne, 1969). The generally coarsening-upward sequence is interpreted as recording the southward progradation of submarine fans during the progressive erosion of an island-arc terrane to the north (McKerrow and Cocks, 1978; Watson, 1981; Arnott, 1983a). Turbidites and conglomerate had been placed into the Sansom Greywacke (Heyl, 1936) and Goldson Conglomerate (Twenhofel and Shrock, 1937) before McKerrow and Cocks (1978) proposed a new formation name, the "Milleners Arm Formation," for both units and the gradational units between them. For mapping convenience, however, the distinction between turbidite and conglomerate units has been maintained (Fig. 2).

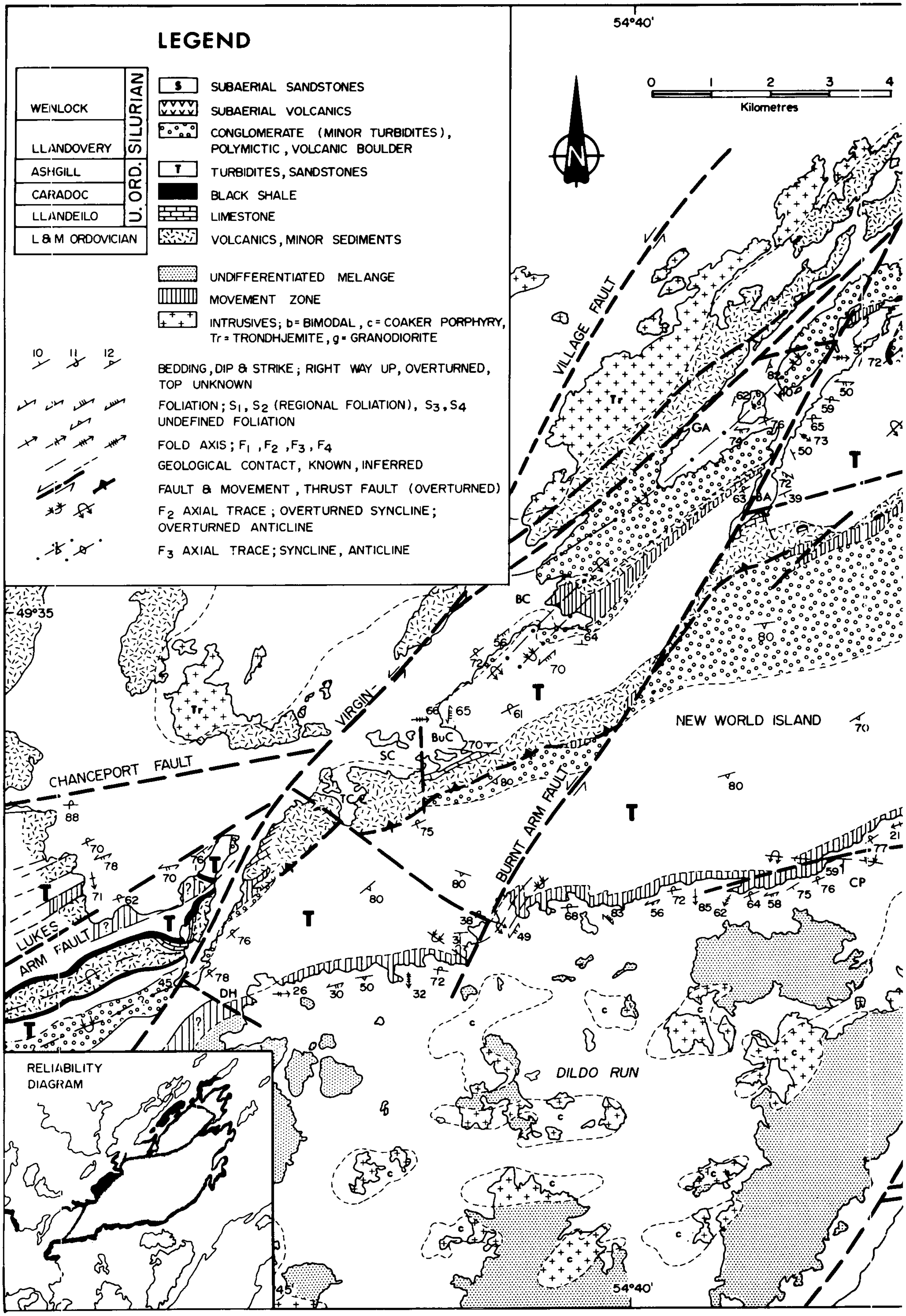
A conglomeratic sequence on northeastern New World Island, the Pikes Arm Formation (Twenhofel and Shrock, 1937), was included with these conglomeratic facies. These comprise the youngest (Upper Llandovery) rocks in the area. McKerrow and Cocks (1978) interpreted this sequence of conglomerate, sandstone, and siltstone with calcareous nodules to be shallow-water sediments. It probably is a transitional sequence between older marine deposits and younger (Wenlock; H. Williams, 1964b) continental volcanics and sandstones. Continental sediments and volcanics are not present on eastern New World Island but are locally thrust over sediments on the Port Albert Peninsula to the south (Fig. 2; Karlstrom and others, 1982). The Upper Llandoverian Joey's Cove mélange (Arnott, 1983a) has been interpreted as a unit deposited during the advance of a thrust sheet (Karlstrom and others, 1983b). Consequently, this mélange is coeval with thrusting, and it is obviously younger than rocks it directly overlies, but is not necessarily the youngest unit in the area. This mélange is not the Dunnage Mélange, and it is placed at the top of the eastern New World Island sequence (Fig. 3).

Lithologic units on eastern New World Island are laterally variable. The southern part of the island is mainly well-bedded turbidites and polymictic conglomerates. The central portion consists of very irregularly bedded sandy turbidites and minor polymictic conglomerates. The northern part is mainly polymictic, red chert and volcanic boulder conglomerates. In addition, individual units exhibit large lateral variations in thickness. From south to the north, turbidites thin until they pinch out in the northern part of the island (Kay, 1969; Arnott, 1983a). A schematic illustration of the rock sequence on eastern New World Island is given in Figure 4.

Furthermore, many of the unconformities proposed by Kay (1976) were not recognized during this study. Many of these were described in areas now recognized as mélange zones or were based on the absence of cleavage at an apparent discontinuity. Postdepositional processes such as mélange development and lithologic contrasts appear to be entirely responsible for these apparent unconformities. As one example, cleavage is commonly not discernible in outcrop, but in thin section, it can easily be demonstrated to cut across many discontinuities.

IGNEOUS ROCKS

Dikes with variable morphologies occur in the study area (Fig. 2). The Ordovician Coaker dacite porphyry (Kay, 1976) is restricted largely to the Dunnage Mélange and locally crops out along the south shore of the island. A different dacite stock is also present along the south shore; it is best exposed in the southwest, near the 370-m.y.-old Upper Devonian Loon Bay Granodiorite (Kay, 1976). The latter exhibit second generation folds and cleavage (discussed below). On the basis of their spatial distribu-


LEGEND
WENLOCK
LLANDOVERY
SILURIAN
ASHGILL
CARADOC
LLANDEILO
U. ORD.
L & M ORDOVICIAN
SUBAERIAL SANDSTONES
SUBAERIAL VOLCANICS
CONGLOMERATE (MINOR TURBIDITES), POLYMICTIC, VOLCANIC BOULDER
TURBIDITES, SANDSTONES
BLACK SHALE
LIMESTONE
VOLCANICS, MINOR SEDIMENTS
UNDIFFERENTIATED MELANGE
MOVEMENT ZONE
INTRUSIVES; b = BIMODAL, c = COAKER PORPHYRY, Tr = TRONDHJEMITE, g = GRANODIORITE
BEDDING, DIP & STRIKE; RIGHT WAY UP, OVERTURNED, TOP UNKNOWN
FOLIATION; S_1, S_2 (REGIONAL FOLIATION), S_3, S_4 UNDEFINED FOLIATION
FOLD AXIS; F_1, F_2, F_3, F_4
GEOLOGICAL CONTACT, KNOWN, INFERRED
FAULT & MOVEMENT, THRUST FAULT (OVERTURNED)
F_2 AXIAL TRACE; OVERTURNED SYNCLINE; OVERTURNED ANTICLINE
F_3 AXIAL TRACE; SYNCLINE, ANTICLINE
54°40'
0 1 2 3 4
Kilometres
N
VILLAGE FAULT
VIRGIN ARM FAULT
CHANCEPORT FAULT
LUKES ARM FAULT
BURNT ARM FAULT
49°35
NEW WORLD ISLAND
DILDO RUN
GA
BA
BC
BuC
SC
TC
DH
CP
Tr
RELIABILITY DIAGRAM

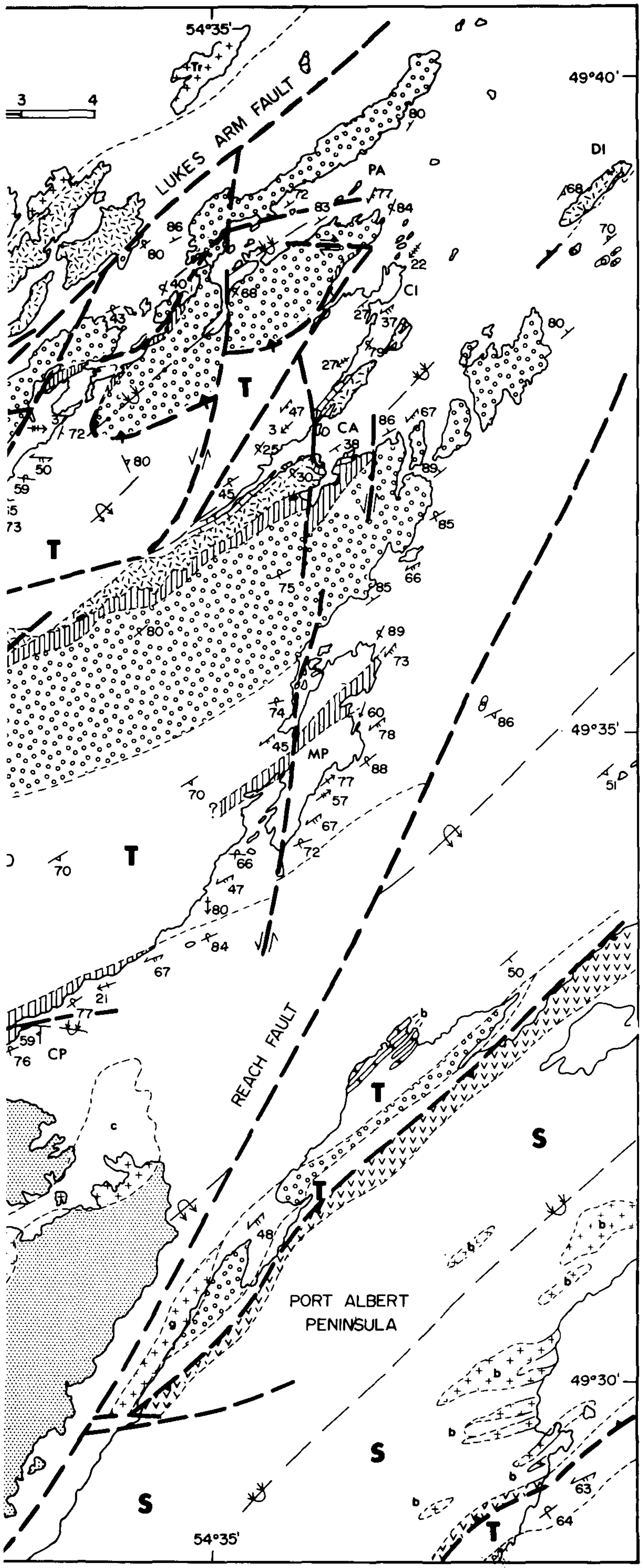


Figure 2. **Geologic map of eastern New World Island. Reliability diagram shows the area where detailed form-surface mapping was carried out; additional mapping by Karlstrom, Reusch, H. Williams, and P. Williams. Locality abbreviations are: BA, Burnt Arm (54°38′, 49°36′); BC, Byrne Cove and Little Byrne Cove (54°41′, 49°35′); BuC, Burnt Cove (54°43′, 49°34′); CA, Cobbs Arm (54°34′, 49°37′); CI, Coopers Island (54°38′, 49°38′); CP, Cheneyville Peninsula (54°38′, 49°33′); DH, Dark Hole (54°45′, 49°31′); DI, Duck Island (54°31′, 49°39′); GA, Goshens Arm (54°39′, 49°37′); MP, Milleners Peninsula (54°34′, 49°35′); PA, Pikes Arm (54°34′, 49°39′); SC, Squid Cove (54°43′, 49°34′); TC, Tilt Cove (54°44′, 49°33′). Note that thrust faults are generally overturned; triangle points toward hanging wall, tick gives direction of dip. (Note overlap in center.)**

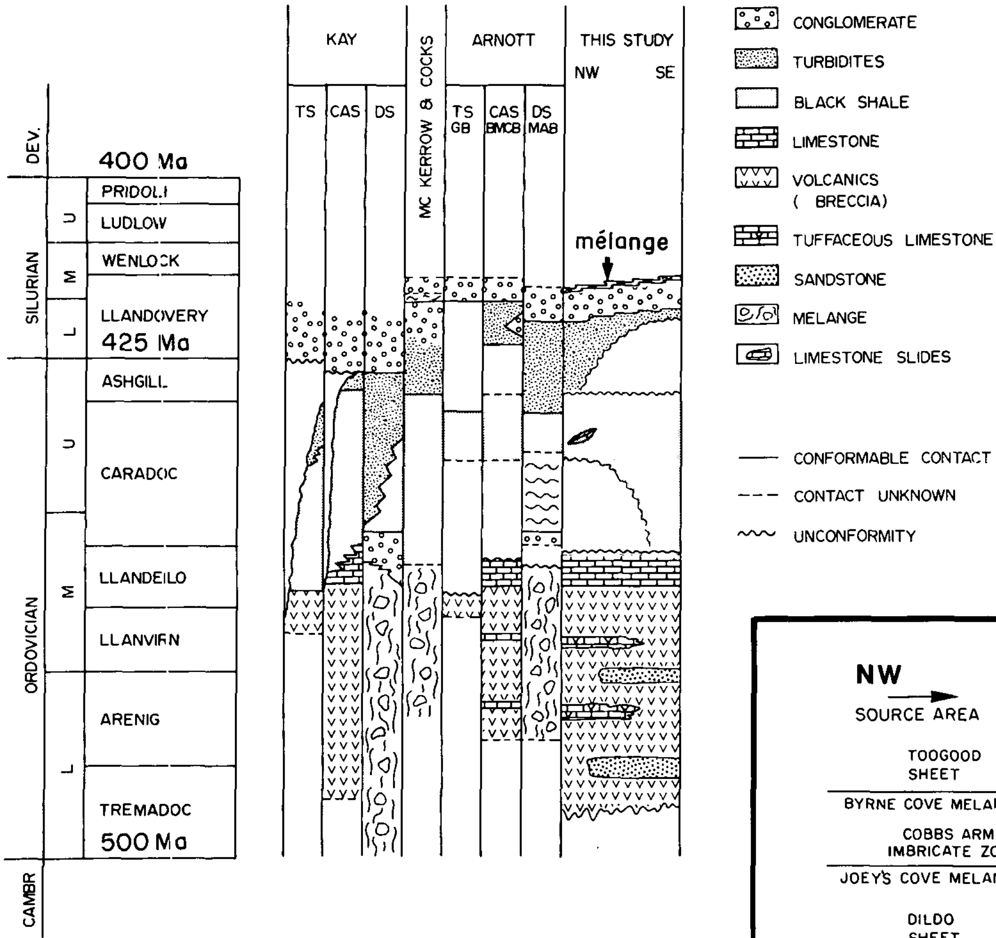


Figure 3. Comparison of stratigraphic sequences on eastern New World Island, proposed by Kay (1976), McKerrow and Cocks (1978), Arnott (1983a, 1983b), and in this study. Abbreviations for sequences are: BMCB, Big Muddy Cove Basin; CAS, Cobbs Arm sequence; DS, Dildo sequence; GB, Goldson basin; MAB, Milleners Arm basin; TS, Toogood sequence. In contrast to the other columns, the Dunnage Mélange to the south is not included in the column labeled "this study." Time scale is after Gale and others (1980).

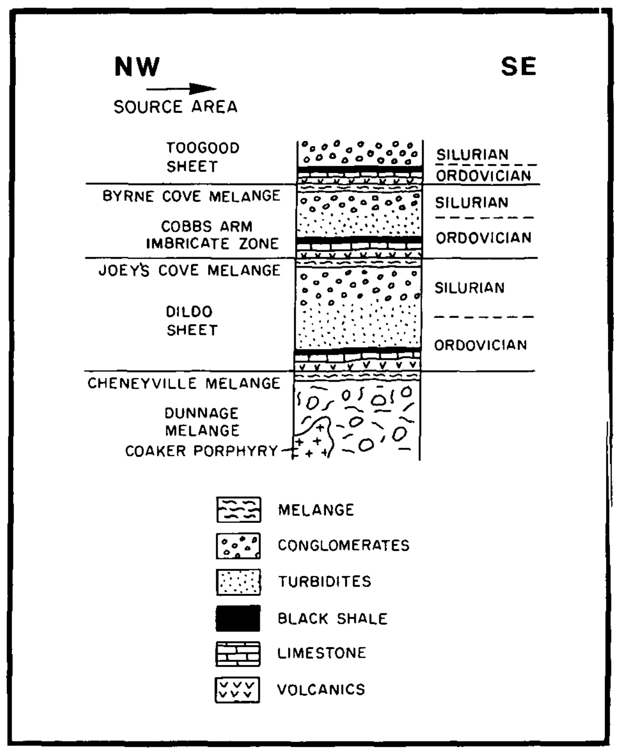


Figure 4. Generalized rock sequence on eastern New World Island. Rock units are not to scale; note the absence of turbidites in the uppermost (Toogood) sheet. Mélange marks the base of the thrusts.

tion and morphological similarity, emplacement of these dacite bodies is tentatively correlated with emplacement of the Loon Bay Granodiorite.

Silicic dikes occur throughout the area (Kay, 1976) and may represent emplacement of differentiates during Devonian plutonism. Lamprophyres also occur in a few localities and are similar to those described by Strong and Harris (1974) from northeastern Newfoundland (see also Helwig and others, 1974); these lamprophyres yield Jurassic ages of 162 ± 5 m.y. (Kay, 1975).

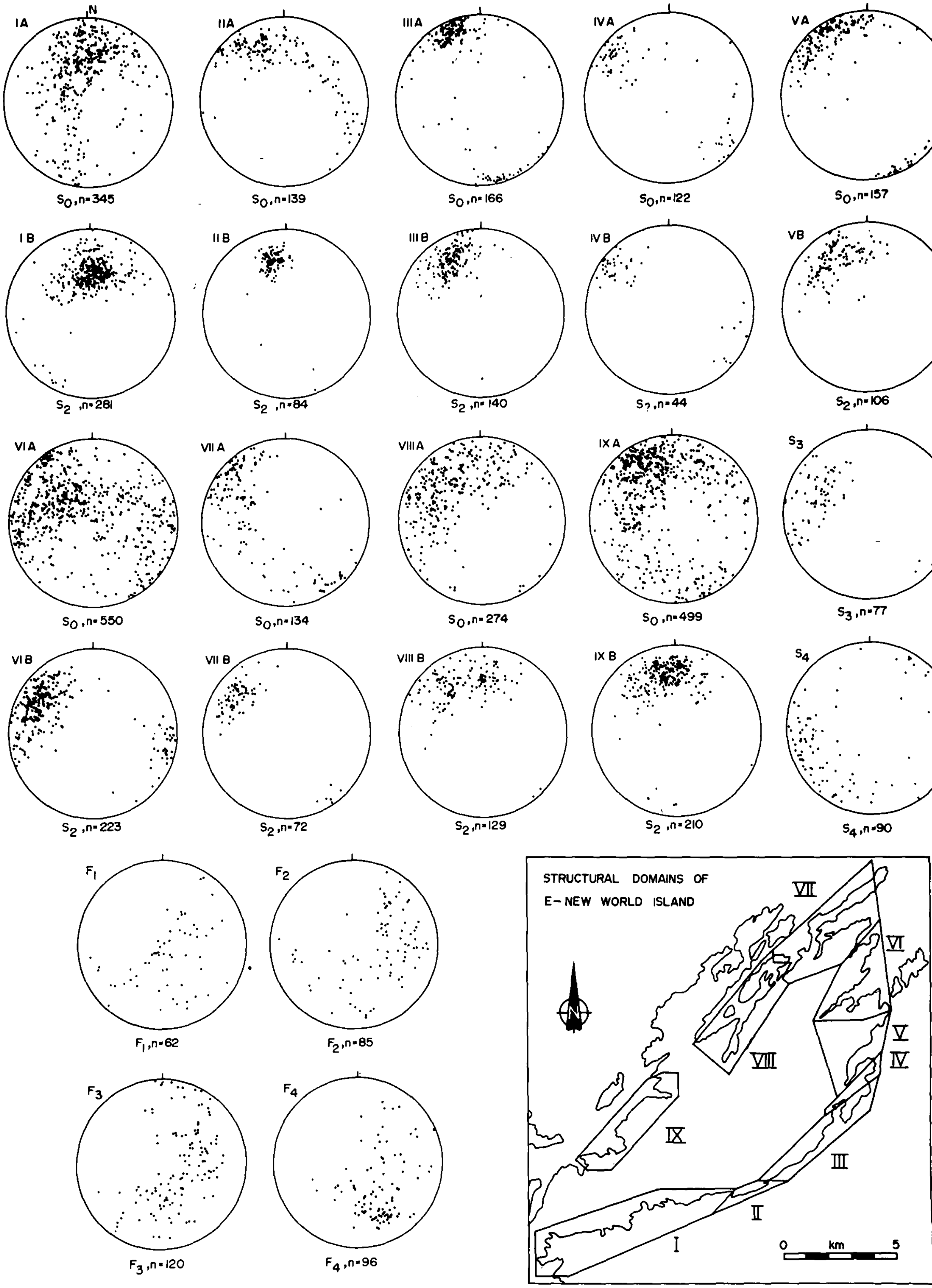
DEFORMATION GENERATIONS

Karlstrom and others (1982) described three generations of deformation in the northeastern Notre Dame Bay area. Additional data collected since that time indicate at least four deformation generations on eastern New World Island. In addition, these data indicate the local presence of a cleavage (S_1) older than the regional cleavage (S_2) and suggest that great caution should be taken in the discrimination of fold generations solely on the basis of relations to regional cleavage (Karlstrom and others, 1982).

In the following sections, the deformation generations will be discussed, with emphasis on D_1. Only through understanding of the effect of superimposed deformation, however, can the history of this area be unraveled.

Recognition of different fold generations is based on overprinting relationships; their style and orientation were used for correlation. Lower-hemisphere, equal-area projections of (S_0) bedding and (S_2) regional cleavage have been determined for nine structural domains (Fig. 5). In order to achieve any higher degrees of cylindricity, it would be necessary to reduce domains to much smaller and impractical sizes, for the area is

Figure 5. Lower-hemisphere, equal-area projections of nine structural domains (inset) on eastern New World Island. Roman numerals correspond to map domains; (A) gives bedding (S_0) pole plots; (B) represents the orientations of poles to S_2. Synoptic diagrams for S_3, S_4, F_1, F_2, F_3, and F_4 are included. The number of measurements (n) for each projection is given.


IA
N
S_0, n=345
IIA
S_0, n=139
IIIA
S_0, n=166
IVA
S_0, n=122
VA
S_0, n=157
IB
S_2, n=281
IIB
S_2, n=84
IIIB
S_2, n=140
IVB
S_2, n=44
VB
S_2, n=106
VIA
S_0, n=550
VIIA
S_0, n=134
VIIIA
S_0, n=274
IXA
S_0, n=499
S_3
S_3, n=77
VIB
S_2, n=223
VIIB
S_2, n=72
VIIIB
S_2, n=129
IXB
S_2, n=210
S_4
S_4, n=90
F_1
F_1, n=62
F_2
F_2, n=85
F_3
F_3, n=120
F_4
F_4, n=96
STRUCTURAL DOMAINS OF
E-NEW WORLD ISLAND
VII
VI
V
IV
VIII
IX
III
II
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0 km 5

heterogeneous on a small scale. Synoptic diagrams for S_3 and S_4 cleavages and for F_1 to F_4 fold axes are also presented (Fig. 5).

D_1 Thrusting

First-generation structures occur in relatively narrow zones. The term "movement zone" is used to describe those areas where this intense and progressive deformation occurred and to emphasize the extremely *heterogeneous* character of D_1 deformation. Because of the progressive nature of this first deformation generation, D_1 is used rather than F_1.

Folds are the most easily recognized features in movement zones. Previous workers paid little attention to these structures, as they were thought soft-sediment deformation features (Kay, 1976) and, therefore, of little importance to the deformation history of the area. Soft-sediment structures have been reported in nearby areas (Helwig, 1970; Horne, 1970); however, such an interpretation for D_1 folds is not supported by evidence on eastern New World Island. Although soft-sediment deformation features, including convoluted bedding, dewatering pipes, and centimetre-scale intraformational faults occur locally, many D_1 structures have demonstrably hard-rock features, such as folded cleavage, which indicate a tectonic origin (see also Karlstrom and others, 1982). Lithologically, these movement zones are characterized by a complex distribution of various rock types.

Evidence for thrusting is the repetition of the general stratigraphic sequence (Figs. 2 and 4). Three major movement zones are recognized which, from north to south, separate the Toogood, Cobbs Arm, and Dildo sequences. These D_1 movement zones and axial surfaces of F_1 folds are approximately parallel to local bedding. Because beds are now generally steeply dipping, it is unlikely that such repetition resulted from dip-slip movement on late subvertical faults, because such a scenario would necessitate large vertical offsets (minimally 7 km along the Dildo sequence–Cobbs Arm sequence boundary). The original configuration of the area would have to have been a steeply dipping sequence with an unrealistic vertical extent of at least 15 km. Furthermore, the uniform lowest greenschist-facies metamorphic grade across the area is inconsistent with such an interpretation. Similarly, it is unlikely that repetition resulted from late strike-slip movements, because the near parallelism between fault and bedding strikes would require very large horizontal displacements (minimally 30 km at the Dildo sequence–Cobbs Arm sequences boundary on a fault less than 40 km in length). Consequently, these relationships require that D_1 structures were originally recumbent and suggest that they are associated with thrusting.

The heterogeneous character of D_1 deformation is most clearly seen in the movement zone exposed on the Milleners Peninsula (Fig. 2). Although biostratigraphic data are not available in this area, sedimentological data from Watson (1981) indicate stratigraphic repetition. The movement zone probably represents relatively minor thrust displacement. Outside the zone, we find steeply dipping, northwest-younging beds, with less steeply southeast-dipping (S_2) cleavage (Fig. 6b). Boudinage in this particular outcrop is the result of later deformation (see later section). Intensely deformed beds occur inside the zone, with upward- and downward-facing folds (Shackleton's facing rule, 1958), indicative of overprinting (Fig. 6d). Transposition of bedding (Fig. 6c) and rootless folds (Fig. 6a) are typical at the inner margins of the zone, reflecting intense deformation near the contact with F_1 relatively undeformed rocks. Locally, these folds are overprinted by a cleavage that is thought to be S_2 cleavage because of its parallelism with S_2 cleavage outside the zone. The structures in this zone are very similar to structures described from thrusted sediments in the central Appalachians (Lash, 1985). Detailed mapping and thin-section study revealed the presence of an older previously unrecognized (S_1) cleavage parallel to zone boundaries (compare Karlstrom and others, 1982, 1983b). Locally, this cleavage is parallel to axial planes of tight F_1 folds; elsewhere, it is folded by F_1. Toward the center of the zone, a composite S_1–S_2 cleavage exists where the distinction between S_1 and S_2 is no longer apparent.

These relationships illustrate the complexity of D_1 deformation. It was not a single deformation episode; rather, it was a *progressive* folding event during which extensive transposition occurred. The asymmetry of minor folds and the over-all zone geometry may indicate northwest-directed movement (Fig. 6).

D_1 deformation structures range in size from centimetres to tens of metres. Spectacular examples occur in a black and light gray shale unit along the south shore of the island. Here, F_1 folds with steeply plunging axes are crosscut by a cleavage which is axial plane cleavage of asymmetrical F_2 folds (Fig. 7). One such fold (Fig. 7b) has the appearance of a sheath fold (for example, Cobbold and Quinquis, 1980). F_1 fold axes vary considerably in orientation within movement zones (Fig. 5), a feature which is considered to be the result of rotation during progressive D_1 deformation. Rotated fold axes occur in areas which have undergone relatively high shear strains and are commonly associated with thrusting (G. Williams, 1978; Cobbold and Quinquis, 1980).

The black and light gray shale unit forms part of a movement zone along the south shore of eastern New World Island (Cheneyville zone, Fig. 4) and includes isoclinally folded, fine-grained turbidites and conglomerates on the Cheneyville Peninsula (Fig. 2). Interpretation of the deformation structures in this area as formed in a D_1 movement zone is in disagreement with interpretations of Kay (1970), Hibbard and Williams (1979), and others who considered the rocks on the Cheneyville Peninsula to be in stratigraphic contact with the underlying Dunnage Mélange. However, the contact is not exposed on the Cheneyville Peninsula, and in Dark Hole (Fig. 2) the contact with the Dunnage Mélange is faulted and not conformable as suggested by Horne (1969).

Thrust contacts are exposed at Rogers Cove and Duck Island (Fig. 8). In Rogers Cove, 500 m south of Cobbs Arm (Fig. 2), a sequence of (Llanvirnian?) basalt, Llandeilian limestone, and Caradocian black shale is separated from structurally underlying Lower Silurian sandstone by a 2-m-wide mélange (Fig. 8a). Blocks in this mélange consist of at least three of the four surrounding rock types. Another thrust contact is present on Duck Island (Fig. 2), where a thick basalt sequence is separated from structurally underlying Caradocian black shale and thin-bedded turbidites by a breccia zone (Fig. 8b). The entire sequence is isoclinally folded and overprinted by a cleavage which is probably S_2 cleavage.

The geometry and distribution of D_1 deformation features vary across the island. In contrast to sections through the Dildo and Toogood thrust sheets, sections across the Cobbs Arm sheet show a large number of D_1 isoclinal folds and bedding reversals. Three general styles of D_1 deformation were distinguished (Fig. 9): (1) movement zones, (2) areas exhibiting little or no evidence of D_1 deformation, and (3) areas other than movement zones that exhibit penetrative D_1 deformation. The over-all structural style of the island, therefore, is not simply one with three relatively undeformed thrust sheets stacked into a thrust pile. Rather, it resembles a duplex system (Dahlstrom, 1970; Boyer and Elliott, 1982) in which the Dildo and Toogood sequences are the floor and roof thrusts, respectively, and the Cobbs Arm sequence is the imbricate zone. Note that rather than being a longitudinal section, the study area represents a section tangential to the direction of movement.

In contrast to the suggestion of Arnott (1983a, 1983b) that D_1 faulting and sedimentation were largely synchronous, repetition of the general

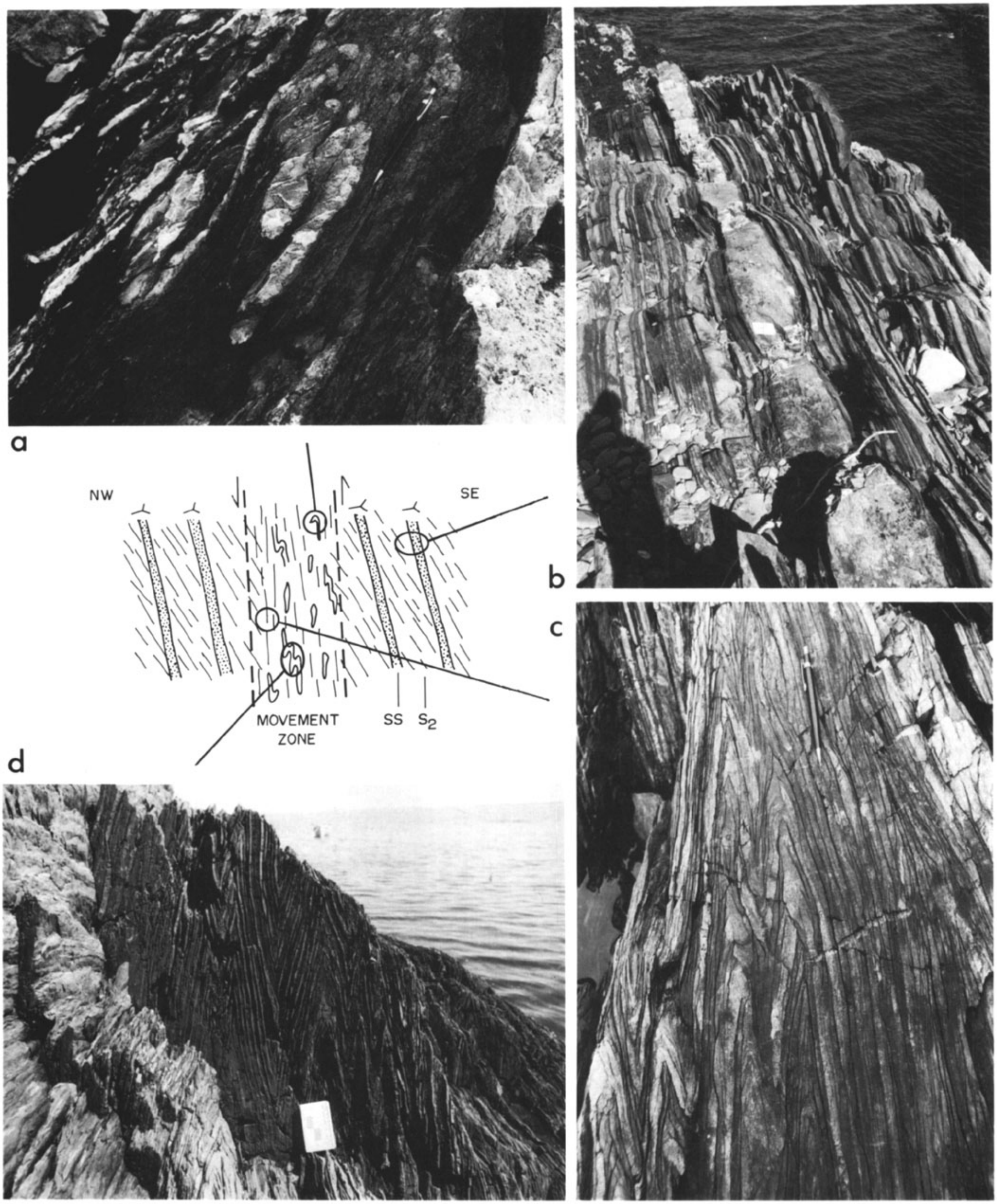

Figure 6. Composite illustration of relationships on the Milleners Peninsula. Areas are shown with relatively undeformed rocks outside the zone (b) and intensely deformed rocks in the zone (d); isolated fold hinges (a) and transposition of bedding (c) are typical of D_1 deformation. Younging is indicated in the sketch of the zone. Pencil length is 13.5 cm; notebook is 19 cm long.

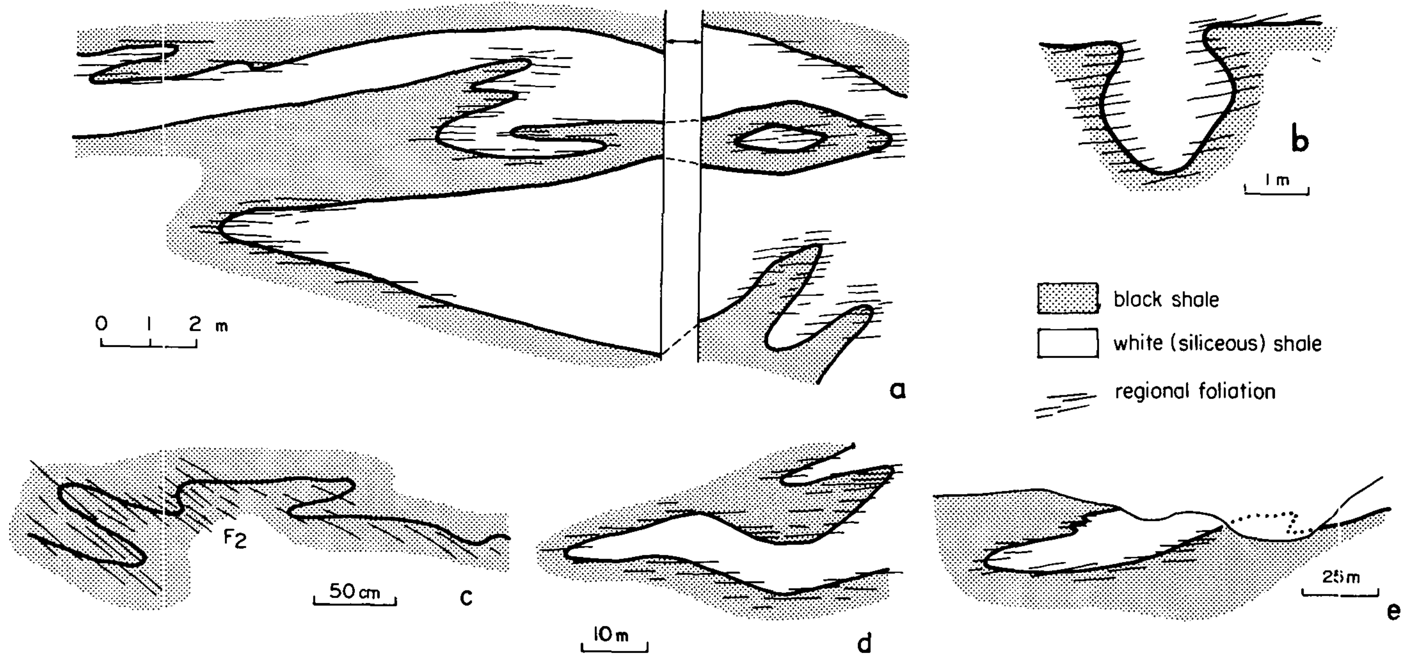

Figure 7. Examples of D_1 structures (form-surface maps) from the south shore of eastern New World Island (low water), 1.5 km west of the Cheneyville Peninsula. The regional cleavage (S_2) crosscuts the folds. East is on the left-hand side in each map.

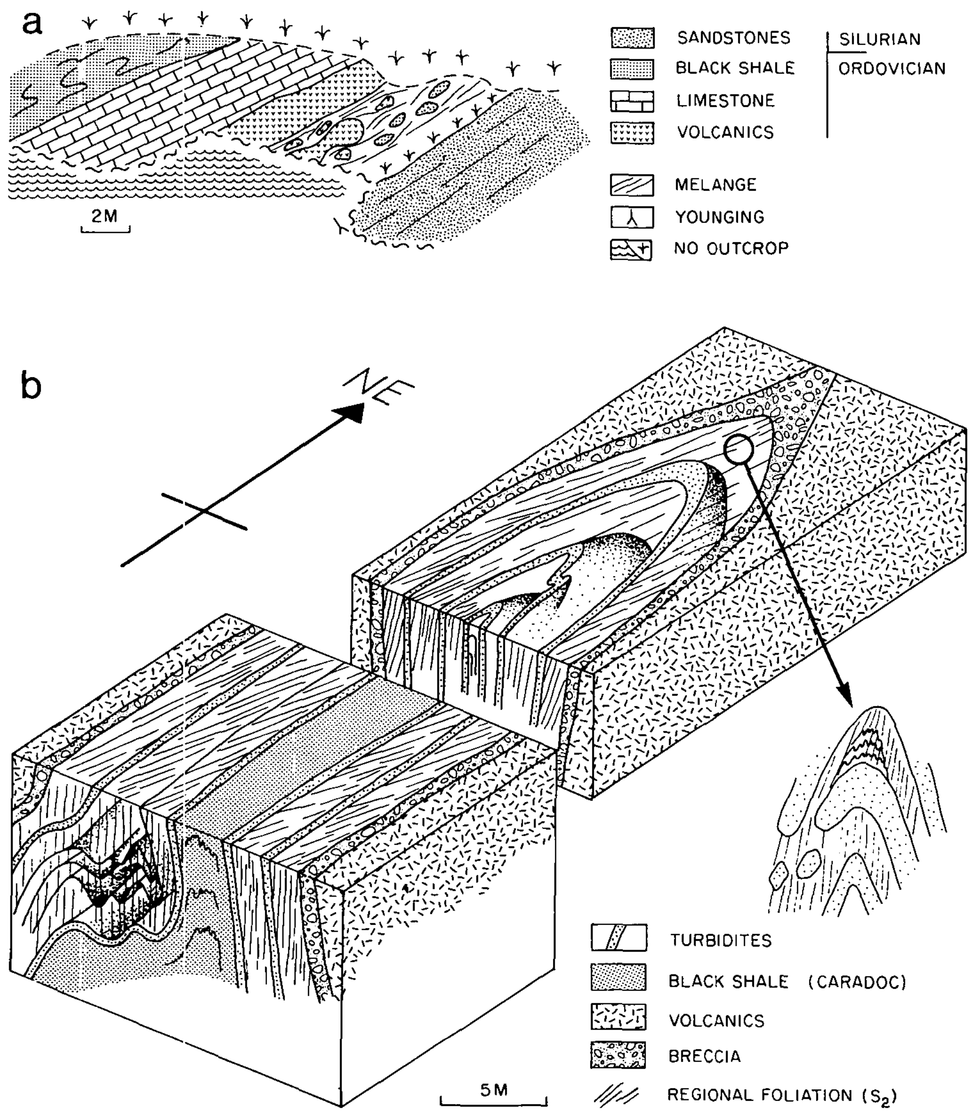

Figure 8. Thrust contacts in the Cobbs Arm area. (a) Thrust contact on the south shore of Rogers Cove. Old-over-young relationship is based on fossil evidence; a mélange unit marks the thrust contact; (b) folded thrust on Duck Island; a breccia is present at the thrust contact.

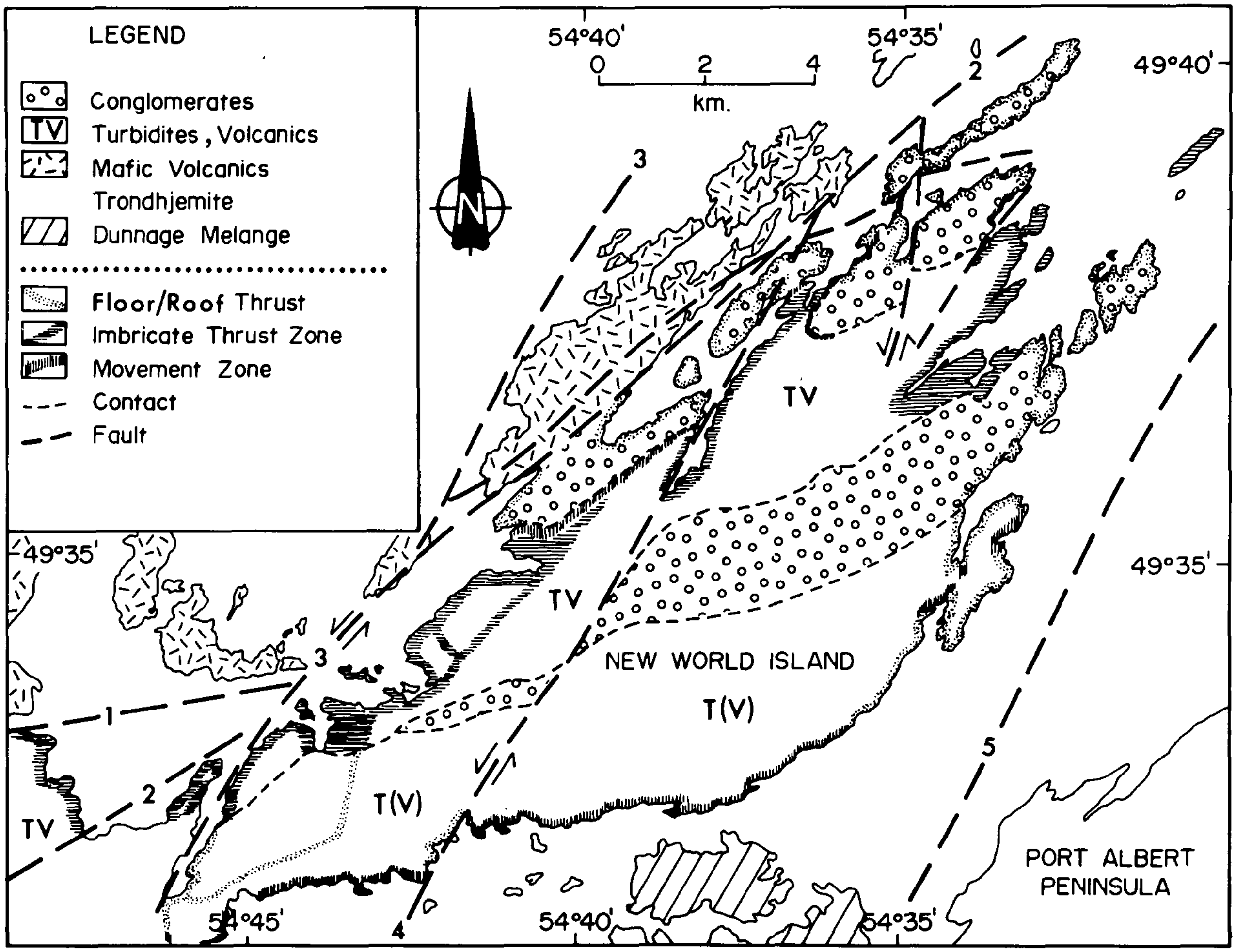

Figure 9. Distribution of D_1 geometries on eastern New World Island. Floor and roof thrusts (stippled) represent the F_1 relatively undeformed sequences (Dildo and Toogood sequences, respectively). The imbricate thrust zone (horizontal ruling) is characterized by an abundance of small-scale thrusts, younging reversals, and F_1 folds (Cobbs Arm sequence). Movement zones (vertical ruling) are defined by bedding transposition and their relatively narrow width. High-angle faults indicated are: 1, Chanceport fault; 2, Lukes Arm fault; 3, Virgin-Village fault; 4, Burnt Arm fault; 5, Reach fault.

stratigraphic sequence and timing of displacement indicate that thrust faulting largely postdated Ordovician through Lower Silurian sediment deposition in this area. Minor deposition associated with Llandovery thrusting occurred locally. These olistostromal deposits or sedimentary mélanges were subsequently deformed into tectonic mélanges by the overriding thrusts.

Although thrusting postdated most sediment deposition, the direction of thrusting is more difficult to establish. Various lines of evidence, such as thickness variations of the three stratigraphic sequences, suggest that thrusting was northwest-directed (van der Pluijm, 1984b). Differences in lithology between the three sequences (Arnott, 1983a), and over-all geometry of the area (van der Pluijm and P. Williams, 1985), however, may suggest southeast-directed thrusting. Minor F_1 folds yield conflicting evidence in that both northwest and southeast vergence have been observed.

F_2 Folding

Second generation folds, with a well-developed S_2 axial plane cleavage, occur throughout the area (see Karlstrom and others, 1982) but are most common near D_1 movement zones. The markedly noncylindrical nature of F_2 folds is demonstrated by the equal-area projection of F_2 axes (Fig. 5). The girdle defined by the spread of F_2 axes coincides with the average S_2 cleavage orientation, which is intermediately to steeply southeast-dipping.

Kilometre-scale F_2 folds are reported from various parts of the Notre Dame Bay area (Karlstrom, 1982; Karlstrom and others, 1982); however, on eastern New World Island, mesoscopic-scale F_2 folds are dominant, with one large-scale fold exposed in the northeastern part of the area (Fig. 10). Figure 10 shows that eastern New World Island is not a simple north-younging homoclinal succession (McKerrow and Cocks, 1978) but, at least in part, is complexly folded.

On a regional scale, two kinematic models can explain the geometry of F_2 structures in the Notre Dame Bay area, where folding defines an approximately horizontal enveloping surface (Karlstrom and others, 1982). In the first model, bedding-parallel crustal shortening formed symmetrical folds, with vertical axial surfaces. These folds were subsequently modified by a simple shear component when folding locked, but the regional shortening continued, resulting in overturned folds. Present geometry requires that this shear movement had a northwest-directed sense. It is possible that this simple shear component was the result of an advancing (F_2?) thrust sheet related to northwest-thrusted rocks exposed on the Port Albert Peninsula. Alternatively, F_2 folding may have been

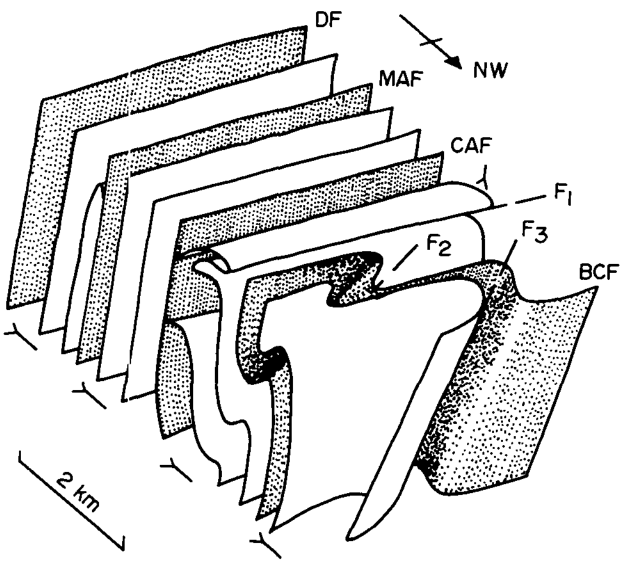

Figure 10. Schematic block diagram of eastern New World Island, looking to the south. Displacements on the Burnt Arm and other faults were restored; younging (arrows) is indicated. Shaded (thrust) planes are: DF, Dildo fault; MAF, Milleners Arm fault; CAF, Cobbs Arm fault; BCF, Byrne Cove fault.

superimposed on moderately northwest-dipping surfaces. Pre-existing dip could have resulted from stacking in an accretionary prism (Seely and others, 1974; Karig and Sharman, 1975). Continued shortening after thrusting then gave rise to asymmetrical folds, notably near zones of high shear strains. A similar mechanism has recently been proposed for the Southern Uplands of Scotland (Stringer and Treagus, 1981; Knipe and Needham, 1985). It is probable that both mechanisms have effected F_2 fold geometries.

F_3 Folding

Third-generation folds have not previously been recognized in this area. Two F_3 fold morphologies are present (Fig. 11). The first type characteristically folds S_2 regional cleavage such that, in profile, interlimb angles of folded bedding are smaller than those of folded cleavages (Fig. 11b). Fold axes are generally steeply plunging. Kinematics of this fold type are discussed by P. Williams (1985). The second type of F_3 folds, on the other hand, have similar bedding-cleavage relationships in fold profile, and fold axes are generally shallowly plunging (Fig. 11c). A weak axial plane cleavage (S_3) is present in the hinges of both fold types. Angular relationships between S_0-S_2 intersections (F_2 fold axes) and F_3 fold axes governs the formation of either fold type (Fig. 11a).

The occurrence of both F_3 fold types is spatially restricted. They are most common in the northern part of eastern New World Island where intense faulting has occurred. The north-northeast trend of these major faults (for example, Burnt Arm fault, Virgin-Village fault; Fig. 2) is approximately parallel to the trace of nearby S_3 axial surfaces (Fig. 5). F_3 deformation is therefore correlated with strike-slip faulting.

F_4 Kinking

The fourth and youngest recognizable fold generation (F_3 in Karlstrom and others, 1982) is represented by conjugate and parallel kinks. The associated kink planes (S_4) are commonly subvertical, although shallow dips do occur (Fig. 5). It is probable that F_4 folding is composed of two or more kink generations, but here they were not distinguished. Large-scale F_4 structures were not recognized on eastern New World Island.

HIGH-ANGLE FAULTS

Two types of high-angle faults are present in the area: strike-slip (transcurrent) faults and dip-slip faults.

Strike-Slip Faults

Large-scale, strike-slip faults divide the Notre Dame Bay area into lozenge-shaped domains (P. Williams, 1984). Eastern New World Island is essentially two domains bounded by the Reach, Virgin-Village, Burnt Arm, and the Lukes Arm faults (Fig. 2). The importance of these transcurrent faults in the area was recognized by Kay (1967, 1976). Horne (1969) showed that the Virgin-Village fault was a sinistral fault with a minimum of 5 km of displacement. The Burnt Arm fault in the central portion of the island parallels the Virgin-Village fault and is also a sinistral fault, with ~2 km of displacement. It exhibits normal drag (Hobbs and others, 1976, p. 306), indicating brittle-ductile behavior during faulting. Dextral faults in the northern part of the island have relatively small offsets; others may have larger displacements, but these are difficult to determine because of the low angle between faults and bedding.

Recent work on the Chanceport fault on western New World Island (Fig. 2) shows that it has predominantly horizontal displacements (S. Armstrong, 1985, written commun.). It has been suggested that transcurrent faults occur in conjugate sets, with sinistral displacements in a south-southeast direction and dextral displacements in east-northeast directions (P. Williams, 1984). Such displacements are in agreement with dextral displacements proposed for both the Lukes Arm and Chanceport faults (Heyl, 1936; Kay, 1967).

The spatial relationship between these faults and the occurrence of F_3 folds in the area indicate that they are related. Strike-slip faulting is considered part of the third deformation generation.

The regional conjugate strike-slip fault set could be a result of approximately northwest-southeast compression, but with an uncommon configuration of σ_1 bisecting the obtuse angle. Alternatively, the area may represent a large transcurrent fault zone that resulted from a difference in motion between the North American–European and African plates (Arthaud and Matte, 1977); the geometry of these faults would indicate dextral movement along the plate boundary. At this stage, it is not possible to distinguish between these possibilities (see also van der Pluijm, in press).

Finally, various small-scale structures are attributed to strike-slip faulting. Boudinage, for example, occurred in competent units. Extensive quartz veining as sigmoidal tension gashes in subvertical boudin necks suggests horizontal extension (Fig. 6b).

Dip-Slip Faults

Subvertical faults with steeply plunging slickensides and fibres are common in the area. Where the Twillingate Highway intersects the volcanic sequence on the central portion of the island, for example, extensive quartz and feldspar veins and epidote and chlorite alteration are associated with these faults. Displacements cannot easily be determined because both faults and beds dip steeply, but they appear to be minor. It is probable that the youngest deformation generation (F_4 kinking) is associated with these faults.

TIMING OF DEFORMATION

Karlstrom and others (1982) have argued for a post–Middle Silurian age for at least a portion of all deformation generations, but they did not preclude the possibility that structures in older rocks could have devel-

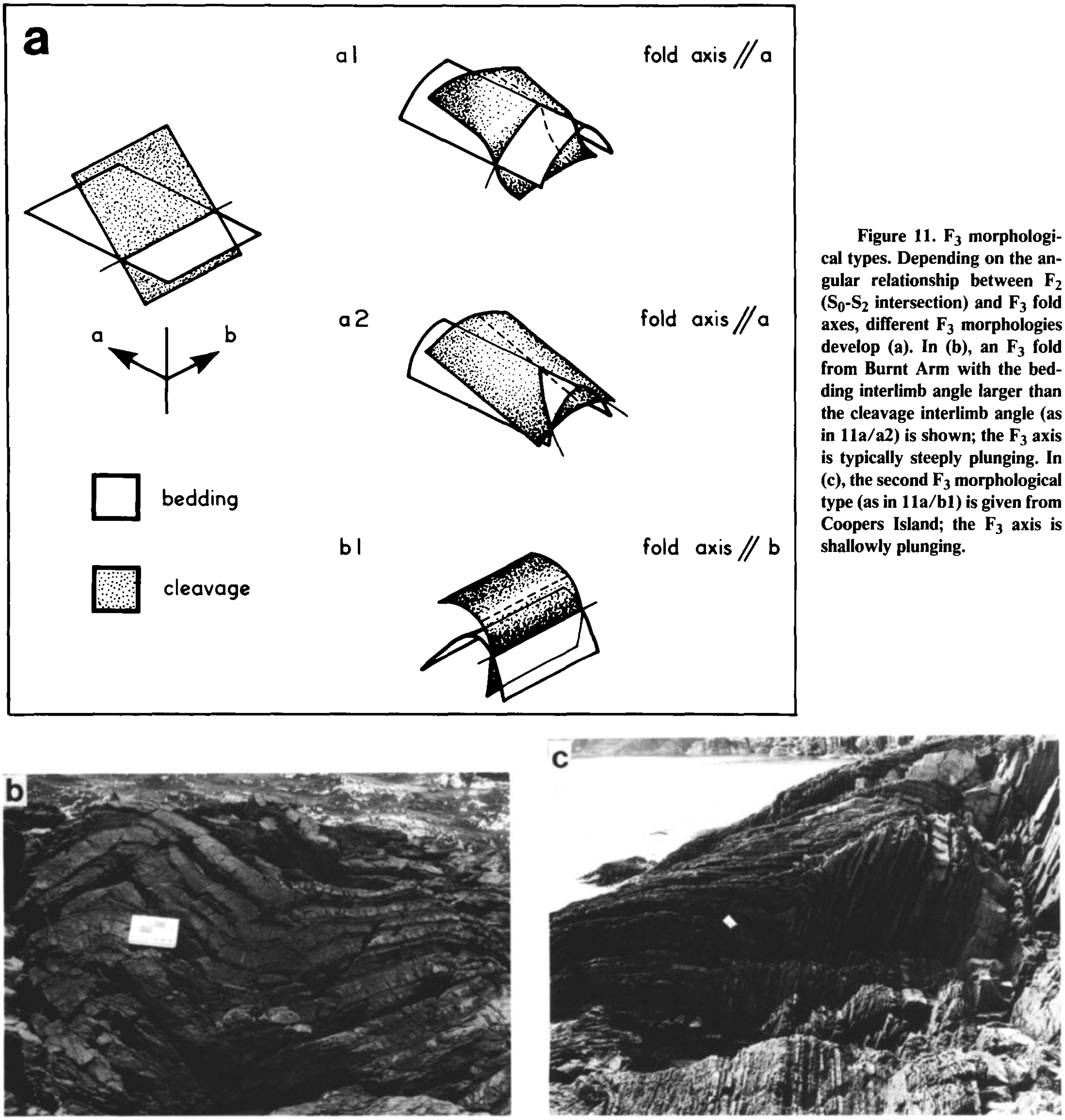

Figure 11. F_3 morphological types. Depending on the angular relationship between F_2 (S_0-S_2 intersection) and F_3 fold axes, different F_3 morphologies develop (a). In (b), an F_3 fold from Burnt Arm with the bedding interlimb angle larger than the cleavage interlimb angle (as in 11a/a2) is shown; the F_3 axis is typically steeply plunging. In (c), the second F_3 morphological type (as in 11a/b1) is given from Coopers Island; the F_3 axis is shallowly plunging.

oped before Middle Silurian times. The presence of a deformed Upper Llandoverian olistostrome dates movement on the Cobbs Arm thrust sheet as Llandoverian (Karlstrom and others, 1983b).

The maximum age of F_2 deformation can be determined from dacite dikes along the south shore of the island that are F_2 folded and show S_2 cleavage. Although these dikes have not yet been dated, it is probable that they are associated with the extensive Devonian regional plutonism, which yielded Devonian radiometric ages (Williams, 1964c; Kay, 1976; Strong and Dickson, 1978). F_2 deformation, therefore, is thought to be Devonian in age.

Silicic dikes overprint F_2 and F_3 folds in the Byrne Cove area (Fig. 2) and Jurassic lamprophyres postdate F_4 structures. A more restricted pre-Jurassic lower age for the various deformation generations will be established when radiometric dates for various dikes become available.

DISCUSSION

Stratigraphic and structural relations discussed above bear directly on the depositional and deformational history of this Paleozoic terrane in the northeastern Appalachians.

Depositional History

In Lower and Middle Ordovician time, deposition of the sequence now exposed on eastern New World Island occurred in a single large sedimentary basin. This basin is interpreted as being associated with a marginal sea which developed southeast of the Ordovician volcanic chain during subduction of the Iapetus Ocean (van der Pluijm, 1984a, in press) rather than as being a remnant of the incompletely closed Iapetus Ocean (H. Williams, 1979).

Relatively shallow water depths for this basin are indicated by the presence of Llandeilian limestones at the top of the volcanic sequence (Dean, 1978). The overlying Caradoc black shale unit represents low rates of sedimentation during a period of basin starvation, either as a result of drowned source areas during eustatic sea-level rise or as a result of deposition in an isolated basin (Watson, 1981). The widespread occurrence of black shales throughout the Appalachian/Caledonian chain (for example, Leggett and others, 1979; Shanmugam and Lash, 1982; Hiscott, 1984) indicates that factors controlling deposition are better explained by a regional flooding than by a series of starved basins separated from their source area. Black shale on eastern New World Island may represent sedimentation in a marginal sea, in which those of Arenigian age in the Dunnage Mélange (Hibbard and others, 1977) represent the oldest sediments deposited on the ocean floor. Geochemical data on volcanic blocks in the Dunnage Mélange (Wasowski and Jacobi, 1985) support this interpretation. Consequently, the Caradocian black shales are time-transgressive equivalents of these ocean-floor sediments. Rapid sea-level rise at the end of Llandeilian time (Cocks and Fortey, 1982) was a contributing factor to the widespread deposition of Caradocian black shale. Late Caradocian to Llandoverian erosion (Dean, 1978) of the volcanic chain, which lay to the north-northwest, supplied volcaniclastics that were deposited on southward-prograding submarine fans (McKerrow and Cocks, 1978; Watson, 1981).

Deformation History

Traditionally the Appalachian orogeny has been subdivided into three major deformation events (H. Williams, 1979; H. Williams and Hatcher, 1983): the Taconic (Ordovician), Acadian (Devonian), and Alleghanian (Carboniferous-Permian) stages. Evidence for Ordovician deformation is not present on eastern New World Island. Here, deformation began in the Lower Silurian and continued into the Devonian (and possibly Carboniferous). Consequently, the upper age limit for the Taconic event or the lower age limit for the Acadian event should be adjusted, or an additional deformation event between Taconic and Acadian deformation should be included. Because deformation is commonly diachronous, addition of yet another deformation event is unwarranted. In view of the characteristics of the Taconic event, such as emplacement of allochthons on Humber zone rocks, it is proposed that the lower age limit for the Acadian event be extended to include Lower Silurian deformation.

The deformation sequence and folding style on eastern New World Island are remarkably similar to those reported from the Southern Uplands of Scotland (see, for example, Stringer and Treagus, 1981; Knipe and Needham, 1985). This area has been interpreted as a Paleozoic accretionary wedge associated with northerly subduction (McKerrow and others, 1977; Leggett and others, 1983). D_1-movement zones were rotated into steeply dipping orientations during continued accretion.

F_2-fold geometry and vergence in the New World Island area are similar to post-S_1 folding in the Southern Uplands. Stringer and Treagus (1981) and Knipe and Needham (1985) suggested that these structures were associated with continued southeast-directed thrusting and associated rotation of individual imbricates. One difference between these areas, however, is the presence of large-scale F_2 folds in the Notre Dame Bay area, such as on the Port Albert Peninsula (Fig. 2).

Back-thrusting in the Southern Uplands, following the steepening of the imbricates, may correlate with northwest-directed thrusting of the continental Botwood Group on the Port Albert Peninsula. Consequently, movement of the Botwood Group is an event unrelated to the formation of the thrust system on eastern New World Island, and correlation between large-scale F_2 folding in the Notre Dame Bay area, which postdates this movement, and F_2 folding in the Southern Uplands may be unjustified. This would explain the parautochthonous nature of the continental unit, where both thrust and transitional contacts with the underlying rocks are present (Karlstrom, 1982; and recent mapping by the writer).

The over-all geometry of eastern New World Island indicates that the deformation regime is not one of simple underthrusting and the development of an imbricate accretionary wedge (Seely and others, 1974; Karig and Sharman, 1975); rather, it represents the formation of an accretionary terrane with considerable internal complexity. It has recently been proposed (Silver and others, 1985) that duplex formation may be an important mechanism during accretion, a suggestion consistent with the geometry of eastern New World Island. In the area to the southwest, tens of kilometre-scale tight folds, crosscut by the regional cleavage, are present (Kean and others, 1981). This indicates that, in addition to duplex formation, early recumbent folds, possibly analogous to structures in the Nankai Trough of southwestern Japan (Moore and Karig, 1976), may also have formed during accretion.

In summary, eastern New World Island in the northeastern Appalachians is considered to be a part of an accretionary terrane with a complex geometry. A more complete understanding of the deformation sequence and geometry in other parts of the Dunnage Zone is essential for an adequate comparison with modern accretionary terranes.

CONCLUSIONS

The following conclusions and regional implications can be made on the basis of the depositional and deformational features exposed on eastern New World Island.

Only one depositional basin was present in this area during the early Paleozoic. Lateral lithofacies variations reflect lateral variations in depositional processes along the basin.

The first deformation generation (D_1) was responsible for the formation of an accretionary wedge that has a complex internal geometry. Evidence for the sense of thrusting yields conflicting directions.

Deformation in the northeastern Dunnage Zone of Newfoundland is Early Silurian and younger in age (Acadian); evidence for earlier (Taconic) deformation is absent.

The deformation sequence and minor fold styles exhibit strong similarity to those in parts of the Southern Uplands of Scotland; however, large-scale F_1 and F_2 folds in the Notre Dame Bay area have not been recognized in the Southern Uplands.

Northwest-directed thrusting of continental rocks on the Port Albert Peninsula may represent a back-thrusting event following the formation of the accretionary wedge. This is a sequence of events analogous to that suggested for the Southern Uplands, and an explanation in agreement with the parautochthonous nature of this unit.

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REFERENCES CITED

Arnott, R. J., 1983a, Sedimentology of Upper Ordovician-Silurian sequences on New World Island, Newfoundland: Separate fault-controlled basins?: Canadian Journal of Earth Sciences, v. 20, p. 345-354.

—— 1983b, Sedimentology, structure and stratigraphy of northeast New World Island, Newfoundland [Ph.D. thesis]: Oxford, England, University of Oxford.

Arnott, R. J., McKerrow, W. S., and Cocks, L.R.M., 1985, The tectonics and depositional history of the Ordovician and Silurian rocks of Notre Dame Bay, Newfoundland: Canadian Journal of Earth Sciences, v. 22, p. 607-618.

Arthaud, F., and Matte, P., 1977, Late Paleozoic strike-slip faulting in southern Europe and northern Africa: Result of a right-lateral shear zone between the Appalachians and the Urals: Geological Society of America Bulletin, v. 88, p. 1305-1320.

Bergstrom, S. M., Riva, J., and Kay, M., 1974, Significance of conodonts, graptolites and shelly faunas from the Ordovician of western and north-central Newfoundland: Canadian Journal of Earth Sciences, v. 11, p. 1625-1660.

Boyer, S. E., and Elliott, D., 1982, Thrust systems: American Association of Petroleum Geologists Bulletin, v. 66, p. 1196-1230.

Cobbold, P. R., and Quinquis, H., 1980, Development of sheath folds in shear regimes: Journal of Structural Geology, v. 2, p. 119-126.

Cocks, L.R.M., and Fortey, R. A., 1982, Faunal evidence for oceanic separations in the Palaeozoic of Britain: Geological Society of London Journal, v. 139, p. 465-478.

Dahlstrom, C.D.A., 1970, Structural geology in the eastern margin of the Canadian Rocky Mountains: Bulletin of Canadian Petroleum Geology, v. 18, p. 332-406.

Dean, P. L., 1978, The volcanic stratigraphy and metallogeny of Notre Dame Bay, Newfoundland: Memorial University of Newfoundland, Geology Report 7, 205 p.

Dean, P. L., and Strong, D. F., 1977, Folded thrust faults in Notre Dame Bay, central Newfoundland: American Journal of Science, v. 277, p. 97-108.

Dean, W. T., 1973, Lower Ordovician trilobites from the Summerford Group at Virgin Arm, New World Island, northeastern Newfoundland: Geological Survey of Canada Bulletin 240, 43 p.

Fahraeus, L. E., and Hunter, D. R., 1981, Paleoecology of selected conodontophorid species from the Cobbs Arm Formation (Middle Ordovician), New World Island, north-central Newfoundland: Canadian Journal of Earth Sciences, v. 18, p. 1653-1665.

Gale, N. H., Beckinsale, R. D., and Wadge, A. J., 1980, Discussion of a paper by McKerrow, Lambert and Chamberlain on the Ordovician, Silurian and Devonian time scales: Earth and Planetary Science Letters, v. 51, p. 9-17.

Harris, I. McK., 1966, Geology of the Cobbs Arm area, New World Island area: Newfoundland Department of Mines, Agriculture and Resources, Mineral Resources Division, Bulletin No. 37, 38 p.

Helwig, J., 1970, Slump folds and early structures, northeastern Newfoundland Appalachians: Journal of Geology, v. 78, p. 172-187.

Helwig, J., Aronson, J., and Day, D. S., 1974, A Late Jurassic mafic pluton in Newfoundland: Canadian Journal of Earth Sciences, v. 11, p. 1314-1319.

Heyl, G. R., 1936, Geology and mineral deposits of the Bay of Exploits area: Geological Survey of Newfoundland Bulletin No. 3, 66 p.

Hibbard, J., and Williams, H., 1979, Regional setting of the Dunnage Mélange in the Newfoundland Appalachians: American Journal of Science, v. 279, p. 993-1021.

Hibbard, J. P., Stouge, S., and Skevington, D., 1977, Fossils from the Dunnage Mélange, north-central Newfoundland: Canadian Journal of Earth Sciences, v. 14, p. 1176-1178.

Hiscott, R. N., 1984, Ophiolitic rocks for Taconic-age flysch: Trace-element evidence: Geological Society of America Bulletin, v. 95, p. 1261-1267.

Hobbs, B. E., Means, W. D., and Williams, P. F., 1976, An outline of structural geology: New York, J. Wiley, 571 p.

Horne, G. S., 1969, Early Ordovician chaotic deposits in the central volcanic belt of northeastern Newfoundland: Geological Society of America Bulletin, v. 80, p. 2451-2464.

—— 1970, Complex volcanic-sedimentary patterns in the Magog Belt of northeastern Newfoundland: Geological Society of America Bulletin, v. 81, p. 1767-1788.

Horne, G. S., and Helwig, J. A., 1969, Ordovician stratigraphy of Notre Dame Bay, Newfoundland, *in* Kay, M., ed., North Atlantic—Geology and continental drift: American Association of Petroleum Geologists Memoir 12, p. 388-407.

Jacobi, R. D., and Schweickert, R. A., 1976, Implications of new data on stratigraphic and structural relations of Ordovician rocks on New World Island, north-central Newfoundland: Geological Society of America Abstracts with Programs, v. 8, p. 206.

Jacobi, R. D., and Wasowski, J. J., 1985, Geochemistry and plate-tectonic significance of the volcanic rocks of the Summerford Group, north-central Newfoundland: Geology, v. 13, p. 126-130.

Karig, D. E., and Sharman, G. F., 1975, Subduction and accretion in trenches: Geological Society of America Bulletin, v. 86, p. 377-389.

Karlstrom, K. E., 1982, Stratigraphic problems in the Hamilton Sound area of northeastern Newfoundland, *in* Current Research, Part B: Geological Survey of Canada Paper 82-1B, p. 43-49.

Karlstrom, K. E., van der Pluijm, B. A., and Williams, P. F., 1982, Structural interpretation of the eastern Notre Dame Bay area, Newfoundland: Regional post-Middle Silurian thrusting and asymmetrical folding: Canadian Journal of Earth Sciences, v. 19, p. 2325-2341.

—— 1983a, Structural interpretation of the eastern Notre Dame Bay area, Newfoundland: Regional post-Middle Silurian thrusting and asymmetrical folding: Reply: Canadian Journal of Earth Sciences, v. 20, p. 1353-1354.

—— 1983b, Sedimentology of Upper Ordovician-Silurian sequences on New World Island, Newfoundland separate fault-controlled basins?: Discussion: Canadian Journal of Earth Sciences, v. 20, p. 1757-1758.

Kay, M., 1967, Stratigraphy and structure of northeastern Newfoundland and bearing on drift in the North Atlantic: American Association of Petroleum Geologists Bulletin, v. 51, p. 579-600.

—— 1969, Silurian of northeast Newfoundland coast, *in* Kay, M., ed., North Atlantic—Geology and continental drift: American Association of Petroleum Geologists Memoir 12, p. 414-424.

—— 1970, Flysch and bouldery mudstone in northeast Newfoundland: Geological Association of Canada Special Paper 7, p. 155-164.

—— 1975, Campbellton Sequence: Manganiferous beds adjoining the Dunnage Mélange, northeastern Newfoundland: Geological Society of America Bulletin, v. 86, p. 105-108.

—— 1976, Dunnage Mélange and subduction of the Protoacadic Ocean, northeast Newfoundland: Geological Society of America Special Paper 175, 49 p.

Kay, M., and Williams, H., 1963, Ordovician-Silurian relationships on New World Island, Notre Dame Bay, northeast Newfoundland [abs.]: Geological Society of America Bulletin, v. 74, p. 807.

Kean, B. F., Dean, P. L., and Strong, D. F., 1981, Regional geology of the Central Volcanic Belt of Newfoundland, *in* Swanson, E. A., Strong, D. F., and Thurlow, J. G., eds., The Buchans Orebodies: Fifty years of geology and mining: Geological Association of Canada Special Paper 22, p. 65-78.

Knipe, R. J., and Needham, D. T., 1985, Deformation processes in accretionary wedges—Examples from the southwestern margin of the Southern Uplands, Scotland, *in* Coward, M. P., and Ries, A. C., eds., Collision tectonics: Geological Society of London Special Publication 19, p. 51-67.

Lash, G. G., 1985, Accretion-related deformation of an ancient (early Paleozoic) trench-fill deposit, central Appalachian orogen: Geological Society of America Bulletin, v. 96, p. 1167-1178.

Leggett, J. K., McKerrow, W. S., Morris, J. H., Oliver, G.J.H., and Phillips, W.E.A., 1979, The north-western margin of the Iapetus Ocean, *in* Harris, A. L., Holland, C. H., and Leake, B. E., eds., The Caledonides of the British Isles—Reviewed: Geological Society of London Special Publication 8, p. 499-511.

Leggett, J. K., McKerrow, W. S., and Soper, N. J., 1983, A model for the crustal evolution of southern Scotland: Tectonics, v. 2, p. 187-210.

McKerrow, W. S., and Cocks, L.R.M., 1978, A lower Paleozoic trench-fill sequence, New World Island, Newfoundland: Geological Society of America Bulletin, v. 89, p. 1121-1132.

—— 1981, Stratigraphy of eastern Bay of Exploits, Newfoundland: Canadian Journal of Earth Sciences, v. 18, p. 751-764.

McKerrow, W. S., Leggett, J. K., and Eales, M. H., 1977, Imbricate thrust model of the Southern Uplands of Scotland: Nature, v. 267, p. 237-239.

Moore, J. C., and Karig, D. E., 1976, Sedimentology, structural geology, and tectonics of the Shikoku subduction zone, southwestern Japan: Geological Society of America Bulletin, v. 87, p. 1259-1268.

Neuman, R. B., 1976, Early Ordovician (late Arenig) brachiopods from Virgin Arm, New World Island, Newfoundland: Geological Survey of Canada Bulletin 261, p. 10-61.

Reusch, D. N., 1983, The New World Island complex and its relationship to nearby formations, north-central Newfoundland [M.Sc. thesis]: St. John's, Canada, Memorial University of Newfoundland.

Seely, D. R., Vail, P. R., and Watson, G. G., 1974, Trench slope model, *in* Burk, C. A., and Drake, C. L., eds., Geology of continental margins: New York, Springer-Verlag, p. 249-260.

Shackleton, R. M., 1958, Downward-facing structures of the Highland border: Geological Society of London Quarterly Journal, v. 113, p. 361-392.

Shanmugam, G., and Lash, G. G., 1982, Analogous tectonic evolution of the Ordovician foredeeps, southern and central Appalachians: Geology, v. 10, p. 562-566.

Silver, E. A., Ellis, M. J., Breen, N. A., and Shipley, T. H., 1985, Comments on the growth of accretionary wedges: Geology, v. 13, p. 6-9.

Stringer, P., and Treagus, J. E., 1981, Asymmetrical folding in the Hawick rocks of the Galloway area, Southern Uplands: Scottish Journal of Geology, v. 17, p. 129-148.

Strong, D. F., and Dickson, W. L., 1978, Geochemistry of Paleozoic granitoid plutons from contrasting tectonic zones of northeast Newfoundland: Canadian Journal of Earth Sciences, v. 15, p. 145-156.

Strong, D. F., and Harris, A. H., 1974, The petrology of Mesozoic alkaline intrusives of central Newfoundland: Canadian Journal of Earth Sciences, v. 11, p. 1208-1219.

Twenhofel, W. H., and Shrock, R. R., 1937, Silurian strata of Notre Dame Bay and Exploits Valley, Newfoundland: Geological Society of America Bulletin, v. 48, p. 1743-1772.

van der Pluijm, B. A., 1984a, Geology and microstructures of eastern New World Island, Newfoundland and implications for the northern Appalachians [Ph.D. thesis]: Fredericton, Canada, University of New Brunswick.

—— 1984b, Geology of eastern New World Island, Newfoundland: A deformed accretionary terrane: Geological Society of America Abstracts with Programs, v. 16, p. 68.

—— in press, Timing and spatial distribution of deformation in the Newfoundland Appalachians: A 'multi-stage collision' orogen: Tectonophysics.

van der Pluijm, B. A., and Williams, P. F., 1985, Fault-controlled stratigraphic repetition in the Notre Dame Bay area, Newfoundland: Geological Association of Canada, Program with Abstracts, v. 10.

Wasowski, J. J., and Jacobi, R. D., 1985, Geochemistry and tectonic significance of the mafic volcanic blocks in the Dunnage Mélange, north-central Newfoundland: Canadian Journal of Earth Sciences, v. 22, p. 1248-1256.

Watson, M. P., 1981, Submarine fan deposits of the Upper Ordovician-Lower Silurian Milleners Arm Formation, New World Island, Newfoundland [Ph.D. thesis]: Oxford, England, University of Oxford.

Williams, G. D., 1978, Rotation of contemporary folds into the X direction during overthrust processes in Laksefjord Finnmark: Tectonophysics, v. 48, p. 29-40.

Williams, H., 1963, Twillingate map area, Newfoundland: Geological Survey of Canada Paper 63-36, 30 p.

—— 1964a, The Appalachians in northeastern Newfoundland—A two-sided symmetrical system: American Journal of Science, v. 262, p. 1137-1158.

—— 1964b, Botwood map area: Geological Survey of Canada Map 60-1963.

—— 1964c, Notes on the orogenic history and isotope ages in the Botwood map-area, northeastern Newfoundland: Geological Survey of Canada Paper 64-17, part II, p. 22-29.

—— 1979, Appalachian orogen in Canada: Canadian Journal of Earth Sciences, v. 16, p. 792-807.

Williams, H., and Hatcher, R. D., Jr., 1982, Suspect terranes and accretionary history of the Appalachian orogen: Geology, v. 10, p. 530-536.

—— 1983, Appalachian suspect terranes, *in* Hatcher, R. D., Jr., Williams, H., and Zietz, I., eds., Contributions to the tectonics and geophysics of mountain chains: Geological Society of America Memoir 158, p. 33-53.

Williams, P. F., 1984, Deformation in the New World Island area, Newfoundland: Late stage transcurrent faulting: Geological Society of America Abstracts with Programs, v. 16, p. 71.

—— 1985, Multiply deformed terrains—Problems of correlation: Journal of Structural Geology, v. 7, p. 269-280.

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