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**GEOLOGY OF LOWER ORDOVICIAN FOSSILIFEROUS  
STRATA BETWEEN VIRGIN ARM AND SQUID COVE,  
NEW WORLD ISLAND, NEWFOUNDLAND**

Gregory S. Horne

**EARLY ORDOVICIAN (LATE ARENIG) BRACHIOPODS  
FROM VIRGIN ARM, NEW WORLD ISLAND,  
NEWFOUNDLAND**

Robert B. Neuman

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## Preface

During recent years, modern theories of plate tectonics have focussed attention on the Ordovician rocks of the central Appalachians. This is particularly true of central Newfoundland, a region undergoing intensive exploration for economic mineral deposits. Fossiliferous beds are not common nor are their contents well preserved, and systematic descriptions of the faunas, such as that now presented for brachiopods of the Summerford Group, are indispensable to the elucidation of the stratigraphy and structural geology.

The two reports that comprise this bulletin are significant contributions to our understanding of the geology of an area that is critical in interpreting the evolution of eastern North America.

*D. J. McLaren*  
Director-General  
Geological Survey of Canada

Ottawa, 2 July 1975



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# GEOLOGY OF LOWER ORDOVICIAN FOSSILIFEROUS STRATA BETWEEN VIRGIN ARM AND SQUID COVE, NEW WORLD ISLAND, NEWFOUNDLAND

Gregory S. Horne

## *Abstract*

Early Ordovician brachiopods, trilobites and other fossils occur in volcanoclastic strata of the Cobbs Arm Sequence exposed along the north-central coast of New World Island at the northern end of Newfoundland's central volcanic belt. The stratigraphic succession has been interpreted as representing the seaward margin of a volcanic island-arc system that was generated by the subductive closure of a hypothetical early Paleozoic seaway.

A pile of Lower and Middle Ordovician submarine basaltic extrusives 300 m thick contains thin and discontinuous beds of calcareous tuff and volcanogenic clastics with shallow-marine fossil assemblages. The volcanics are succeeded by about 10 m of fossiliferous Middle Ordovician limestone, which is overlain by approximately 75 m of black, graptolitic Upper Ordovician argillite. The upper part of the succession consists of 50 m of penecontemporaneously distorted pelitic strata that gradationally coarsen upwards into well stratified greywacke of Late Ordovician and Early Silurian age.

The stratigraphic sequence may be correlated with both the Summerford Group to the southwest and the Hillgrade Group to the northeast. The faunas are characterized by peculiar generic associations, some of which are unknown elsewhere. Paleogeographic interpretations suggest the faunas inhabited coastal waters surrounding volcanic isles within an Early Ordovician ocean.

## *Résumé*

On trouve des brachiopodes, des trilobites et d'autres fossiles de l'Ordovicien inférieur dans les couches pyroclastiques de la succession de Cobbs Arm exposées le long du centre de la côte nord de l'île New World qui se trouve à l'extrémité nord de la région volcanique du centre de Terre-Neuve. On a considéré que cette succession stratigraphique représentait la marge côtière d'un ensemble d'îles formées par un arc volcanique qui serait dû à la fermeture par enfouissement d'un détroit hypothétique du Paléozoïque inférieur.

Un amoncellement de 300 mètres d'épaisseur de roches extrusives, basaltiques et sous-marines de l'Ordovicien inférieur et moyen, contient de minces lits discontinus de tuf calcaire, de roches clastiques d'origine volcanique et des assemblages de fossiles marins d'eau peu profonde. Environ 10 mètres de calcaire fossilifère de l'Ordovicien moyen se superpose aux roches volcaniques et est recouvert par approximativement 75 mètres d'argilite graptolitique noire de l'Ordovicien supérieur. La partie supérieure de la succession est constituée par 50 mètres de couches de pélite déformées peu de temps après leur sédimentation et qui deviennent graduellement plus grossières en approchant de la surface où elles sont composées de grauwacke clairement stratifié de l'Ordovicien supérieur et du Silurien inférieur.

On peut établir une corrélation entre cette succession stratigraphique et les groupes de Summerford au sud-ouest et de Hillgrade au nord-est. Les faunes se caractérisent par des associations particulières de genres dont certains ne se retrouvent pas ailleurs. Les interprétations paléogéographiques portent à croire que les faunes vivaient dans des eaux littorales qui entouraient des îles volcaniques de l'océan au cours de l'Ordovicien inférieur.

## Introduction

Early Ordovician brachiopods, trilobites and other fossils are found in scattered and discontinuous sequences of volcanogenic sedimentary strata within a thick accumulation of submarine extrusives which is exposed along the north-central coast of New World Island, Newfoundland. The stratigraphy of these rocks and details of the local geology are given in this paper. In the accompanying paper, Neuman describes the systematics of brachiopod faunas collected from various localities.

New World Island is at the northern end of the axial zone of the Appalachians; it lies within eastern Notre Dame Bay off the northeast coast of Newfoundland (Fig. 1). Dewey

(1969) first suggested that the Appalachian record in Newfoundland might be interpreted in terms of the modern hypotheses of seafloor spreading and plate tectonics; this concept was further elaborated to apply to the entire Appalachian Belt (Bird and Dewey, 1970). The most recent summary of the tectonic evolution of the Canadian Appalachians (Williams, Kennedy and Neale, 1972) also utilized the same synthesizing concepts of plate tectonics. The essence of these paleotectonic interpretations is that during the Early Paleozoic the central mobile belt of Newfoundland occupied an oceanic position within a hypothetically closing Proto-Atlantic Ocean that separated two converging continental masses. The supporting evidence from Notre Dame Bay (Horne and Helwig, 1969; Helwig and Sarpi, 1969; and Kay, 1969) is of Early Ordovician volcanic islands, open-ocean pelagic deposits, chaotic sedimentary mélanges, Late Ordovician flysch troughs, plutonism and molasse basins.

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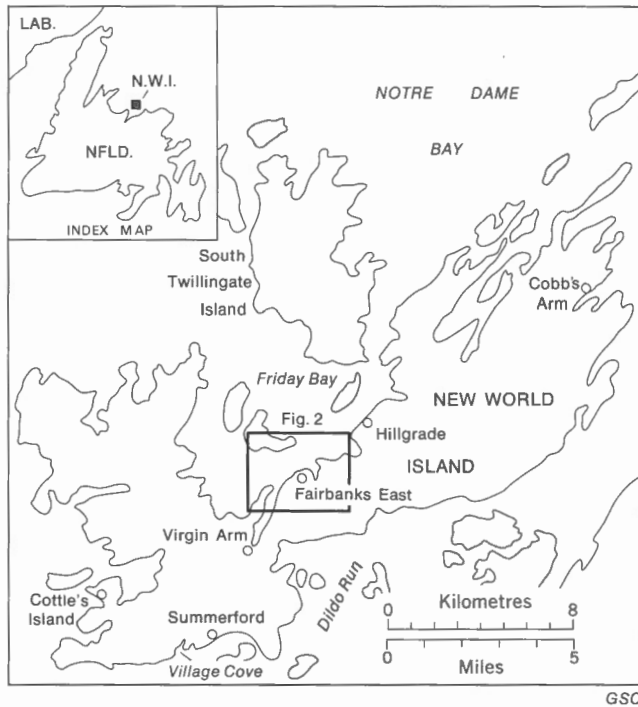


Figure 1. Index map of New World Island, Newfoundland.

Horne (1970) cited evidence from New World Island that suggested the area represented the seaward margin of an Early Ordovician volcanic island arc generated by the subduction of a plate of Proto-Atlantic seafloor. The Luke's Arm Fault divides the area into a northwestern terrane dominated by volcanic piles more than 10 km thick (Strong and Payne, 1973), and a somewhat thinner southeastern terrane of mixed sedimentary and volcanic strata. These juxtaposed lower Ordovician terranes have been interpreted as representing a northwestern island arc and a southeastern forearc margin and trench system (Horne, 1970; Mitchell and Reading, 1971; Strong and Payne, 1973).

Ordovician faunas from New World Island have been described by several workers. Bergström, Riva and Kay (1974) summarized the Middle and Late Ordovician biostratigraphy of conodont and graptolite faunas from throughout New World Island. Dean described Early Ordovician trilobite faunas from Squid Cove (Dean, 1971) and Virgin Arm (Dean, 1974) on the north-central coast of New World Island (Fig. 2); these sites are further described herein. Neuman (1968, 1971, 1972) has previously referred to Early Ordovician brachiopod faunas from New World Island.

A persistent and perplexing problem concerning brachiopod faunas from the area is the peculiar association of species that were previously not believed to coexist in time or space, a homogenization of distinctly different provincial faunas and a mixture of what seems to be geologically young and old faunal elements. Neuman (1972) accounted for the mixture of the faunas by employing the earlier paleogeographic interpretations in an evolutionary context. He suggested that coastal waters around Early Ordovician volcanic isles provided the right combination of

genetic insularity and diverse environments to promote the development of new stocks, representatives of which migrated to continental margins later as the Proto-Atlantic closed.

## General Geology

Lower Paleozoic rocks in the Notre Dame Bay region are thick, heterogeneous, generally unfossiliferous, laterally variable, and have been highly deformed into complex structures. Modern studies in the New World Island area commenced with mapping by Williams (1963); he divided the succession of marine volcanic and sedimentary strata into unnamed lithic map-units. Williams recognized that the region was broken by major faults into northeast-trending structural-stratigraphic blocks. Kay (1967) defined three stratigraphic sequences exposed within separate blocks south of the Luke's Arm Fault on New World Island. The Ordovician stratigraphy of these sequences has been described in several papers in which the names of various units were formalized (Kay and Eldredge, 1968; Horne and Helwig, 1969; Horne, 1969, 1970; Kay, 1969, 1970; Bergström, *et al.*, 1974).

### Structural Setting

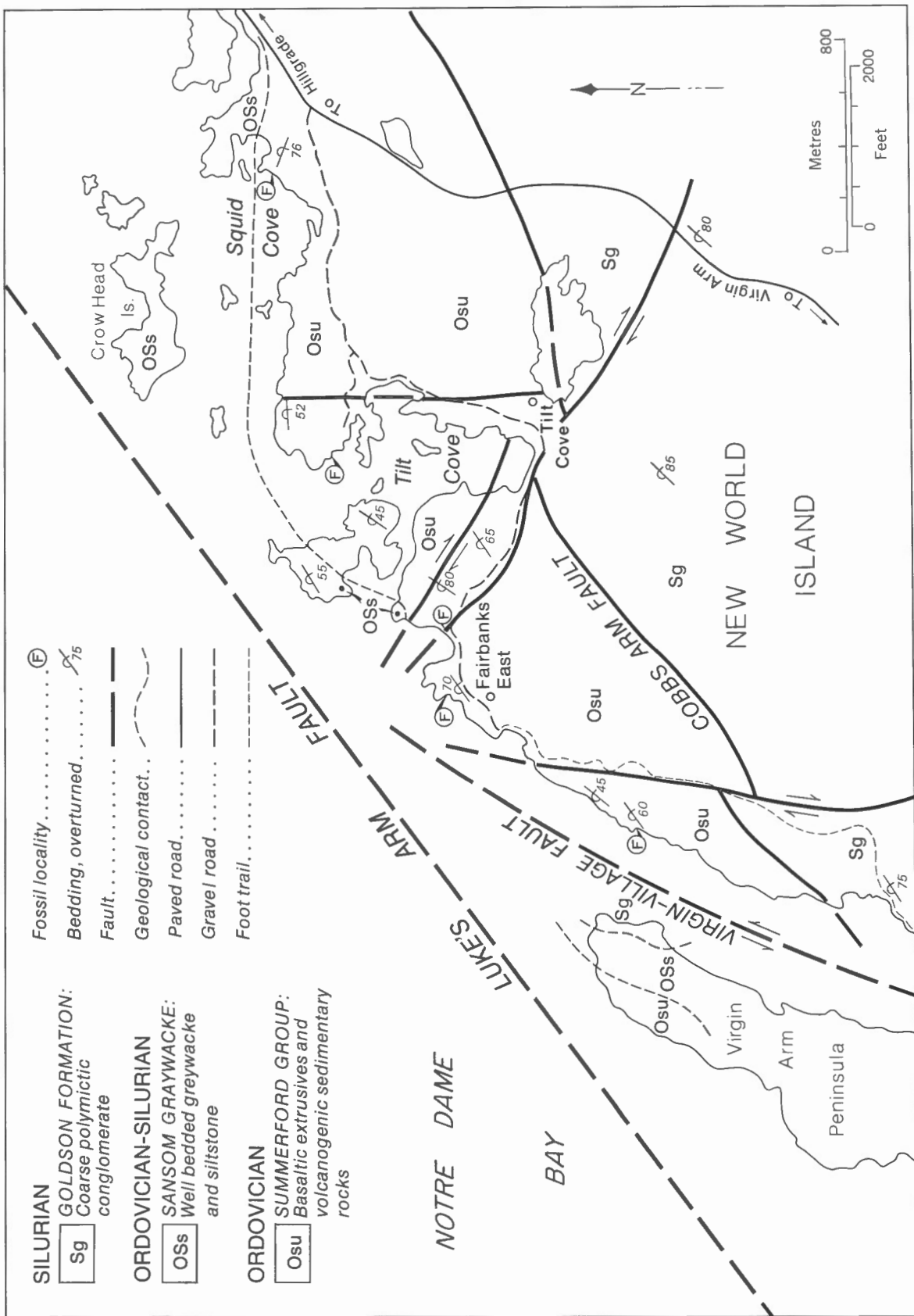
Fossiliferous strata exposed along the north-central coast of New World Island between Virgin Arm and Squid Cove are the subject of this report (Fig. 2). These exposures lie less than 1 km southeast of the Luke's Arm Fault. The Cobbs Arm Fault juxtaposes the Silurian Goldson Formation against these rocks only 1 km farther to the southeast. Thus the fossiliferous strata described in this report clearly lie within the Cobbs Arm Sequence as originally defined (Kay, 1967, p. 588).

The Virgin-Village Fault is a major northeast-trending sinistral fault that lies just west of the subject area. Ordovician strata exposed west of the Virgin-Village Fault were originally assigned to the Cobbs Arm Sequence (Horne, 1970) but have been subsequently renamed the Virgin Arm Sequence (Bergström, *et al.*, 1974).

The rocks exposed in the area strike northeast and generally dip steeply southeast. Primary sedimentary structures indicate that most of the succession is overturned and faces northwest towards the Luke's Arm Fault. Therefore these rocks must occupy the overturned south limb of a major synclinal fold that has been broken by the Luke's Arm and Cobbs Arm faults. The Virgin-Village Fault and at least four other faults cut across the succession in the subject area (Fig. 2).

### Stratigraphy

The Summerford Group was defined (Horne, 1970, p. 1770) to apply to Ordovician volcanic and related sedimentary rocks throughout the lateral extent of the Cobbs Arm Sequence on New World Island; it was named from exposures along the shore of Summerford Arm on southwestern New World Island. In that area the Summerford Group was informally divided into three sedimentary units with intervening volcanic members (*see* Table 1). The Summerford Group is directly and conformably overlain by



GSC

Figure 2. Generalized geological map of north-central coast of New World Island; modified after Horne, 1970.

Table 1. Composite sections of Ordovician strata, Cobbs Arm Sequence, New World Island

AGE	LOCATION	Summerford - Virgin Arm areas (southwestern New World Island)	Fairbanks East - Squid Cove areas (north-central New World Island)	Hillgrade - Cobbs Arm areas (northeastern New World Island)
SILURIAN ?		Sansom Graywacke		
	LATE VIC	chaotic unit		
MIDDLE OD		upper volcanic unit	Unit 7 greywacke	
	EARLY OD	Caradocian argillite	Unit 6 distorted clastic strata	
		(limestone member)	Unit 5 black argillite	
		middle volcanic unit	Unit 4 limestone	
			Unit 3 basaltic extrusives and volcanic clastic strata	
		arkosic unit	Unit 2 feldspathic greywacke	
		lower volcanic unit	Unit 1 basaltic extrusives	
SOURCE :		Horne, 1970	this report	modified after Bergström, et al., 1974

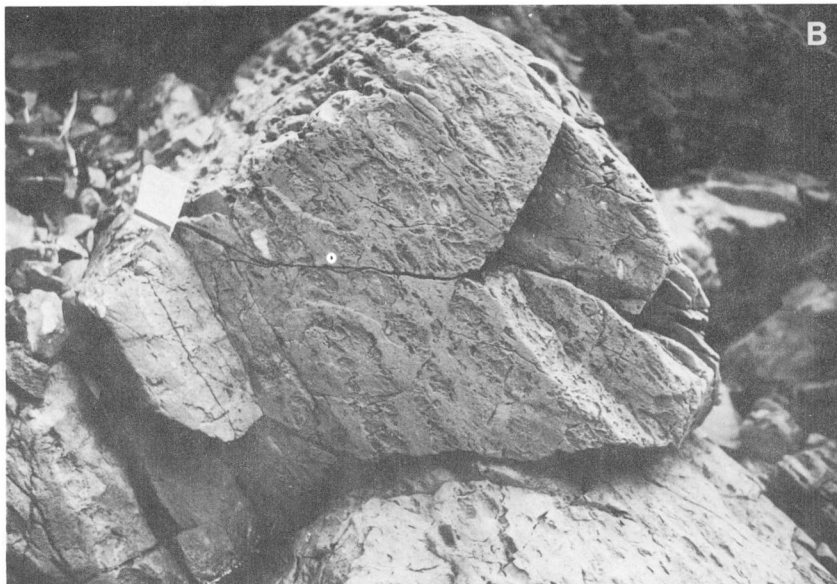


Figure 3. A. Fossiliferous calcareous tuff bed at Virgin Arm locality (Unit 4 of measured section). View looking southwest; 15-cm scale rests on contact with overlying, unfossiliferous, volcaniclastic sandstone. B. Fossiliferous volcaniclastic sandstone at west beach of Fairbanks East (Unit 3 of measured section). View of near-vertical joint face, looking northeast along strike. Note that the more calcareous parts, somewhat recessed, are in discontinuous beds. Matchbook at left is 38 mm wide.

the Sansom Graywacke, which presumably is Late Ordovician and Early Silurian.

Kay (1969, p. 415) recognized three Ordovician formations on northeastern New World Island: volcanics and associated sedimentary strata that he referred to the Summerford (Formation); the Hillgrade Formation, which consists of three members — lower tuffs and pyroclastic deposits, an intervening limestone exposed at the Cobbs Arm quarry and an upper argillite with Caradoc graptolites; and the Sansom Graywacke. The Hillgrade was later raised to group status and its upper two members were named the Cobbs Arm Limestone and the Rodgers Cove Shale (Bergström, *et al.*, 1974); the lower volcanogenic member was included within the underlying Summerford (*see* Table 1).

Fossiliferous Ordovician rocks have been found at several localities within the Cobbs Arm Sequence exposed between Virgin Arm and Squid Cove. The details of the succession at each of these localities are described below. Tentative correlations with other sections are suggested in the conclusions.

#### *Virgin Arm*

The Virgin Arm fossil locality (GSC locality 92034) is on the east shore of Virgin Arm, about 2.8 km north-northeast of the government wharf at Virgin Arm Village, and due east of the small settlement at the northeast tip of the Virgin

Arm Peninsula (Fig. 2). Grid location is 624906, Zone 21, Twillingate 2E/10 West Half topographic sheet. The shore in this vicinity is steep and relatively straight, with no prominent landmarks; the most conspicuous feature nearby is an isolated pinnacle of volcanic rock about 17 m north of the exposed fossiliferous bed. The azimuth from the locality to the northernmost visible tip of the Virgin Arm Peninsula is  $292^\circ$ . In favourable weather the locality can be reached by small boat; overland it is accessible via the trail south from the end of the road at Fairbanks East, then a short distance through thick brush to the shore.

About 500 kg of large angular blocks of fossiliferous calcareous tuff were collected here in 1967. These blocks yielded the fossils described in the accompanying report by Neuman and that by Dean (1974). A bed of tuff 1 m thick and identical to that of the blocks crops out at the locality. This bed and associated volcaniclastic sedimentary rocks are minor components of a sequence composed predominantly of extrusive volcanic rocks of Unit B, the middle volcanic unit of the Summerford Group (Horne, 1970, p. 1771, section 5 of Fig. 4). Approximately 7 m of volcanogenic sedimentary strata are exposed between thick accumulations of extrusive rocks at the site (Fig. 3A). The strata dip steeply southeast, are not folded on a mesoscopic scale and are unbroken by major faults. Cross laminations indicate that the strata are overturned and face northwest. A description of the local section follows:

Unit	Description	Thickness	
		of unit	above base
		(m)	
7	Extrusives, basaltic, dark greenish grey; massive flows with some pillows. Unit 7 includes pinnacle at shoreline.	4	23
6	Covered interval.	6	19
5	Sandstone, volcanoclastic, greenish grey, medium to coarse grained; well bedded.	4	13
4	Tuff, grey, fine grained to silty; thinly interbedded with calcareous layers which produce a ribbed weathered surface (see Fig. 3A); richly fossiliferous with brachiopods and trilobites (see Dean, 1974). GSC loc. 92034	1	9
3	Sandstone, volcanoclastic, greenish grey, medium grained; well bedded with minor crossbedding in thin coarse-grained sets	1	8
2	Breccia and conglomerate, tuffaceous and volcanoclastic, variegated purple to green, pebbly; massive, extensively marbled with carbonate; few low-spined gastropods.	1	7
1	Breccia and agglomerate, basaltic, dark greenish grey, coarse to cobbly; massive; limy interstitial fillings and thin calcite veins. Unit 1 forms the sea cliff above the exposed fossiliferous beds.	6	6

*Fairbanks East*

Fossils were found and collected in 1973 at two places in Fairbanks East, both within the middle part of the Summerford Group.

*West beach.* Just west of the main cove of Fairbanks East (Fig. 2), fossiliferous beds were found at the north end of a small beach facing west (GSC locality 92035); grid location is 630913, Zone 21, Twillingate 2E/10 East Half topographic sheet. Road access is easy, continuing approximately 150 m west of the major wharf in the Fairbanks East cove, with a short walk northwest to the beach.

The fossiliferous beds occur within a thick sequence of basaltic extrusive rocks like those that enclose the fossiliferous beds at the Virgin Arm locality. Although a north-trending dextral fault was mapped between the two localities, details of the stratigraphy suggest that displacement along this fault is small and that the fossiliferous beds are 100 to 200 m stratigraphically above those at Virgin Arm. Approximately 12 m of sedimentary strata are exposed at the north end of the beach. No evidence of faulting or mesoscopic folding is locally apparent. Criteria for stratigraphic facing were not found, but the fossiliferous strata dip steeply southeast and project northeast some 100 m along strike to other steeply south-dipping exposures of similar strata that are overturned according to the criteria of graded bedding. Details of the local section are at the top of the next column.

*Main cove.* Brachiopods and other fossils were found in 1973 in a roadside exposure just above the east end of the beach of the main cove at Fairbanks East (GSC locality 92036). This locality is on the northwest flank of a low hill immediately east of the road, at the intersection of a driveway with the through road. Grid location is 633914, Zone 21, Twillingate 2E/10 East Half topographic sheet.

The exposure includes about 8 m of greyish purple

Unit	Description	Thickness	
		of unit	above base
		(m)	
5	Extrusives, basaltic, dark grey; massive to pillowed. Thickness of Unit 5 is measured only to the rocky point immediately northwest of the beach.	10	31
4	Sandstone, volcanoclastic, dark grey, coarse grained to pebbly; irregular beds about 8 cm thick; beds alternately more or less calcareous, yielding a ribbed weathered surface.	7	21
3	Sandstone, volcanoclastic, grey, fine grained; well bedded; contains discontinuous lenses of calcareous rock which weather to a pitted surface (see Fig. 3B); abundant brachiopods, especially near the top of the unit. GSC loc. 92035.	4.5	14
2	Covered interval, beach deposits.	7	9.5
1	Breccia, basaltic, dark greenish grey; interstices laced with calcite. Unit 1 is exposed in low outcrops at the northern part of the beach.	2.5	2.5

pebbly volcanoclastic sandstone. Fossils were found only near the middle of the exposed sequence, in a poorly defined calcareous zone about 0.3 m thick, which is conspicuously weathered, brown and porous. Clasts in this rock are red fine-grained volcanic rock, some of which is amygdular; most are rounded coarse sand grains, but rounded pebbles as much as 20 mm in diameter are common. Beds dip 75° southeast and presumably face northwest, consistent with others in the area.

Similar but unfossiliferous sandstone outcrops on the shore at the west end of the main cove. A northwest-trending fault with dextral displacement passes through the main cove of Fairbanks East (Fig. 2). If the sandstones in the two exposures are correlative, strata at the fossil locality are estimated to be 50 to 60 m stratigraphically beneath the fossiliferous strata exposed at the west beach locality; the intervening section consists of basaltic extrusive rocks.

*East of Fairbanks East*

The relationship of medial Ordovician fossiliferous rocks previously reported (Williams, 1963; Kay, 1967; Dean, 1971) from the Squid Cove area, 1.7 miles northeast of Fairbanks East, to older fossiliferous rocks of the Summerford Group can be demonstrated in the shoreline exposures between Squid Cove and Tilt Cove (Fig. 2). Throughout these exposures, wherever stratification is orderly, the beds dip steeply south and sedimentary structures consistently indicate that the beds are overturned and face northward.

At the east, on the north headland of Squid Cove, sandstone characteristic of the Sansom Graywacke is exposed. On small islands next to the south shore, thinly interbedded greywacke, siltstone and argillite are complexly deformed. These strata are very similar to the rocks of Unit E, the chaotic unit of the Summerford Group exposed farther southwest on New World Island (Horne, 1970, p. 1773).

Volcanic rocks of Unit D, the upper volcanic unit of the Summerford Group, commonly underlie the sedimentary

rocks of Unit E throughout most of southwestern New World Island, but there are none at Squid Cove. Instead, the deformed interbedded clastic strata that are exposed on the islands in the eastern part of Squid Cove are demonstrably underlain by Caradoc black argillite similar to Unit C of the Summerford Group. Exposures of the argillite extend across the tidal flat to the islands and also line the south shore of the eastern subcove of Squid Cove. Graptolites were obtained from these shore exposures (Williams, 1963, p. 8; Toghil in Dean, 1971, p. 31, 32, GSC locs. 52294, 86163; Bergström, *et al.*, 1974). The outcrop width of the argillite unit is about 100 m, but the thickness cannot be determined because of complex internal deformation.

Limestone outcrops along the shore west of the argillite exposures in Squid Cove, but about 12 m of rock, including the argillite-limestone contact, are covered by beach deposits. The limestone appears to be a thin representative of the Cobbs Arm Limestone, which is much thicker to the east but only discontinuously exposed to the west. Details of the succession are as follows:

Unit	Description	Thickness	
		of unit	above base (m)
5	Limestone, medium to dark grey; well interbedded calcarenite, calcilutite, and nodular beds; minor thin beds of black argillite; sparsely fossiliferous with trilobite debris. GSC loc. 85524.	3	9
4	Limestone, medium to dark grey, calcilutite; ribbon-laminated; argillaceous partings.	2.5	6
3	Limestone, dark grey, calcarenite; nodular, in argillaceous matrix.	1.5	3.5
2	Limestone, medium to dark grey, calcilutite; ribbon-laminated.	1.5	2.0
1	Limestone, medium grey, coarse calcarenite; thick bedded.	0.5	0.5

The trilobites described by Dean (1971) and the conodonts studied by Uyeno (*in Dean*, 1971, p. 37) from Unit 5 of this section indicate a late Llandeilo age, about the same as that of the Cobbs Arm Limestone reported elsewhere on New World Island (Bergström, *et al.*, 1974).

Beds of green pyroclastics and fragmental volcanic debris directly underlie the limestone with apparent conformity. Such beds, together with volcanic breccia, agglomerate and bedded tuff breccia, are exposed westward through the Squid Cove settlement. West and south of Squid Cove these rocks are underlain by a massive pile of basaltic extrusive rocks that include a few lenses of coarse pelmatozoan calcarenite. This assemblage of rocks is characteristic of Unit B, the middle volcanic unit of the Summerford Group, and is nearly continuously exposed along the coast of the headland between Squid Cove and Tilt Cove.

On the east shore of Tilt Cove (grid location 639918, Zone 21, Twillingate 2E/10 East Half topographic sheet) trilobites and a few brachiopods were found in two thin beds of fine-grained grey tuffaceous limestone (GSC locality 90809). Each of the limestones is contained within a sequence of bedded calcareous tuff 2 to 3 m thick, occurring within a

much thicker sequence of extrusive basalt that probably belongs to the lower part of Unit B of the Summerford Group. Well bedded feldspathic greywacke like that of Unit A, the arkosic unit of the Summerford Group, is exposed on the peninsula and nearby island south of the fossiliferous beds.

## Conclusions

Although each of the sections described in this report is separated from the other sections by major faults (Fig. 2), we may reasonably utilize lithic character and stratigraphic position to correlate the various fossil sites that are exposed between Virgin Arm and Squid Cove. On the basis of these criteria, a reconstructed stratigraphic sequence for the area is presented in Table 2. This composite section may then be compared with other described sections elsewhere on New World Island (Table 1) to suggest tentative lithic correlations of Ordovician strata in the Cobbs Arm Sequence (Table 3).

Table 2: Reconstructed stratigraphic sequence exposed along north-central coast of New World Island

Unit	Approx. thickness (m)	Lithic description	Location
7	>100	Well bedded greywacke and subgreywacke	Northeast headland of Squid Cove, and north-western part of Tilt Cove Island
6	50	Interbedded greywacke, siltstone, and argillite; penecontemporaneously deformed	Islets within eastern subcove of Squid Cove
5	75	Black graptolitic argillite	South shore of eastern subcove of Squid Cove
4	10	Interbedded calcarenite and calcilutite	Southeast shore of Squid Cove
3	300	Basaltic extrusives with interlayered pyroclastic deposits and calcareous volcanogenic strata	Shores of western Squid Cove, northern Tilt Cove, Fairbanks East, and northeastern Virgin Arm
2	50	Feldspathic greywacke	Presqu'isle in eastern Tilt Cove
1	>200	Basaltic extrusives with interlayered coarse pyroclastics and limy tuffs	South shore of Tilt Cove and along north side of Cobbs Arm Fault

Table 3: Tentative lithic correlations of Ordovician strata, Cobbs Arm Sequence, New World Island

This report	Williams, 1963	Horne, 1970	Bergström, <i>et al.</i> , 1974
Unit 7	Map-unit 8	Sansom Graywacke	Sansom Graywacke
Unit 6	(not separated)	Summerford Unit E	(not recognized)
Unit 5	Map-unit 7	Summerford Unit C	Rodgers Cove Shale
Unit 4	Map-unit 6	Summerford Unit B	Cobbs Arm Limestone
Unit 3	Map-unit 4	Summerford Unit B	Summerford Volcanics
Unit 2	Map-unit 5	Summerford Unit A	—
Unit 1	Map-unit 4	Summerford Unit Z	—

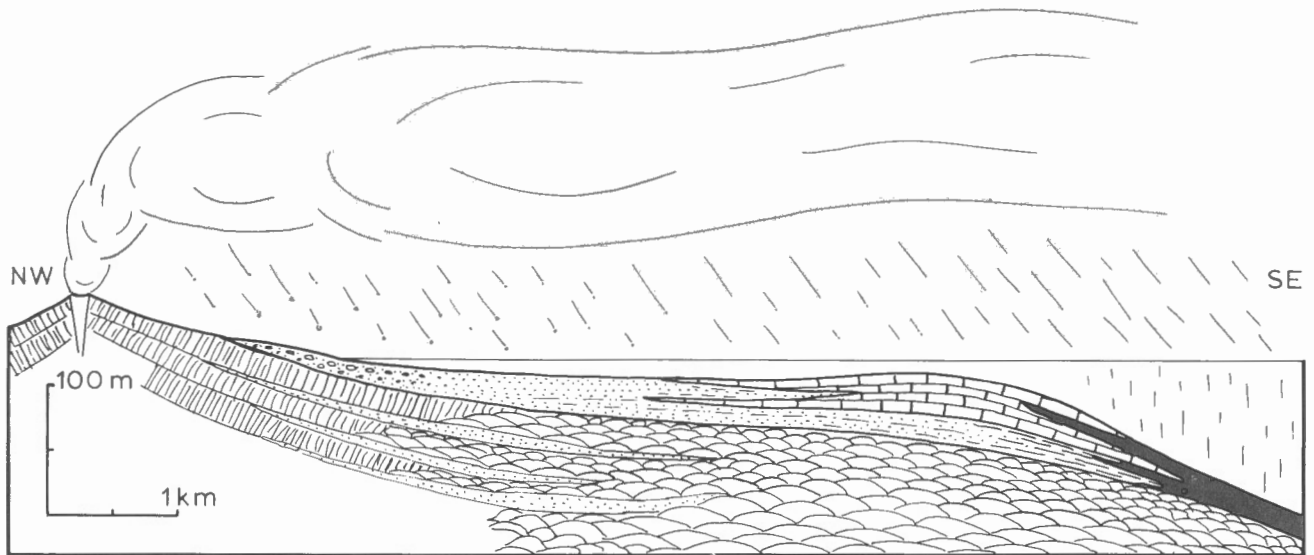


Figure 4. Hypothetical restored section of the Summerford Group showing depositional environments in medial Ordovician time; symbols as on Table 1; black denotes pelagic mud.

Some of the units exposed around Squid Cove have been referred to the Hillgrade Group on northeastern New World Island (Bergström, *et al.*, 1974). All of these units are also recognizable within the Summerford Group on southwestern New World Island. The upper part of the Summerford Group to the southwest seems obviously to correspond with the Hillgrade Group to the northeast. Although details of the succession are different in each area, the data presented here show that the two groups interfinger throughout the length of New World Island.

The biogenic calcareous strata at Squid Cove (Unit 4) are considerably less extensive than the limestones exposed either at Cobbs Arm on northeastern New World Island or at Cottle's Island on southwestern New World Island (*see* Fig. 1). Although they occur at about the same stratigraphic level from locality to locality, the limestones are discontinuous and do not constitute a distinct stratigraphic belt (*see* Williams, 1963, p. 8; or Horne and Helwig, 1969, p. 394).

Still, conodont zonation indicates that the carbonate rocks exposed at Cobbs Arm, Squid Cove and Cottle's Island are approximately correlative (Dean, 1971; Bergström, *et al.*, 1974). We may reasonably assume that biogenic calcareous sediment accumulated contemporaneously in various localized environments as fringing banks around isolated volcanic shoals or islands (as is presently taking place in the Lesser Antilles) and, therefore, were not preserved in lithic continuity.

Calcareous tuffs and other sublittoral volcanogenic deposits occur at various stratigraphic levels within the volcanic accumulations on New World Island. Some of these deposits have yielded shallow-marine fossil assemblages that are described in the following paper by Neuman. These communities probably also inhabited coastal waters surrounding volcanic isles within a closing Ordovician sea (Fig. 4). It is within this paleogeographic framework that the peculiar generic associations may be understood in an evolutionary context.

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# EARLY ORDOVICIAN (LATE ARENIG) BRACHIOPODS FROM VIRGIN ARM, NEW WORLD ISLAND, NEWFOUNDLAND

Robert B. Neuman

## Abstract

Fossiliferous volcanoclastic beds among extrusive rocks of the middle volcanic unit of the Summerford Group at four places on New World Island indicate marine environments from beneath the euphotic zone to very shallow water around volcanic islands in the Proto-Atlantic Ocean. Of the 27 brachiopod species from calcareous tuff at Virgin Arm, six are placed in new genera, one each in new species of *Atelelasma* and *Ahtiella*, and others are assigned with varying degrees of confidence to established genera of the Baltic and Scoto-Appalachian biogeographic provinces. Comparison is closest with the late Arenig brachiopods of Anglesey, northwestern Wales, suggesting extension of the Celtic biogeographic province to include such peri-insular occurrences.

## Résumé

Les lits fossilifères de roches volcano-clastiques qui se trouvent parmi les roches effusives au centre de l'unité volcanique du groupe de Summerford témoignent en quatre endroits de l'île New World de la présence de milieux marins s'échelonnant de la zone euphotique aux eaux très peu profondes autour des îles volcaniques de l'océan proto-atlantique. Parmi les 27 espèces de brachiopodes trouvées dans le tuf calcaires de Virgin Arm on en a classé six dans de nouveaux genres, une dans chacune des nouvelles espèces d'*Atelelasma* et d'*Ahtiella*, et les autres sont placées avec différents degrés de certitude dans des genres connus des provinces biogéographiques baltique et scoto-appalachienne. On note une ressemblance très nette avec les brachiopodes de l'Arenig supérieur d'Anglesey, au nord-ouest du pays de Galles, ce qui suggère que la province biogéographique pourrait s'étendre au delà des îles où de tels faits se sont manifestés.

## Introduction

Brachiopods, trilobites and other fossils of probable late Early Ordovician (late Arenig) age have been found in four places on New World Island in volcanoclastic rocks intercalated with extrusive rocks of the middle volcanic unit (Unit B) of the Summerford Group. The richest and most diversified assemblage of brachiopods occurs in calcareous tuff at Virgin Arm (GSC locality 92034). These fossils are described in this report; the trilobites associated with them were described by Dean (1974). Similar brachiopods occur in tuff near Village Cove (Neuman, 1968, 1971) and smaller assemblages were found in volcanoclastic sandstone at two places near Fairbanks East. Together, these fossils afford a sample of the benthonic fauna in the waters surrounding a volcanic island in the Proto-Atlantic Ocean.

A generous sample of about 500 kg of blocks of calcareous tuff was collected at Virgin Arm by G. S. Horne in 1967 and sent to me in Washington. The size of this sample proved to be essential in obtaining the material described here. When Horne and I examined the Virgin Arm locality together in 1973, we found the Fairbanks East localities.

The continuing advice and encouragement of G. A. Cooper of the U. S. National Museum of Natural History are gratefully acknowledged, as is the help of Valdar Jaanusson of the Swedish National Museum of Natural

History, Stockholm. G. S. Horne, who prepared the preceding report in this bulletin, provided invaluable guidance and geological information during our visit together to New World Island in 1973. The indispensable co-operation of officers of the U.S. Geological Survey and the Geological Survey of Canada in the support of this international undertaking is also gratefully acknowledged.

## Environmental Indications of the Fossiliferous Beds

Although all the fossiliferous rocks are of volcanodetrital origin, each has its own petrographic and paleontological characteristics that suggest sedimentary and environmental differences. The considerable overlap of the occurrence of brachiopods among the four localities (*see* table) indicates that these rocks are essentially contemporaneous. Differences, therefore, seem primarily to be due to variations in depth and turbulence of water.

Nearshore turbulent shallow water is recorded by the red volcanic detritus with its abundance of molluscs and abraded brachiopods at the main cove of Fairbanks East. The poorly bedded tuff at the Village Cove locality probably represents deepest water accumulation. Intermediate water depth, within the euphotic zone, is indicated for the other two localities; the coarser grained rock with its less diverse fauna at the west beach of Fairbanks East probably

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Counts of brachiopod specimens identified from samples of fossiliferous beds at Virgin Arm (A), Village Cove (B), Fairbanks East, west beach (C) and Fairbanks East, main cove (D).

Brachiopods	A	B	C	D
<i>Orthisocrania</i> sp.	5			
<i>Multispinula</i> sp.		3		
<i>Orthambonites</i> sp.	60	59	6	16
<i>Productorthis mainensis</i> Neuman	68	63	22	
<i>Glypterina</i> sp.	38			
<i>Plectorthis</i> sp.	38	5		
<i>Platystrophia?</i> sp.	7			8
<i>Acanthorthis terreneuvensis</i> n. gen., n. sp.	9			
<i>Paurorthis</i> sp.	49			
<i>Virgoria virgensis</i> n. gen., n. sp.	25		3	
<i>Eodalmanella</i> sp.		47		
<i>Atelelasma atlanticus</i> n. sp.	83		1	
<i>Fistulogonites novaterrens</i> Neuman		7		
<i>Progonambonites</i> sp.	30			
<i>Tritoechia billingsi</i> Neuman	22	16	2	18
<i>Jaanussonites hornei</i> n. gen., n. sp.	27			
<i>Antigonambonites</i> sp.	19			
<i>Ingria</i> sp.	29	4		18
<i>Ahtiella paucirugosa</i> n. sp.	31	34	1	15
<i>Guttasella gutta</i> n. gen., n. sp.	4			
<i>Inversella</i> sp.	6			
<i>Taffia?</i> sp.	22	6		
<i>Calypsolepta diaphragma</i> n. gen., n. sp.	79		3	2
<i>Anechophragma rarum</i> n. gen., n. sp.	4			
aff. <i>Bimuria</i> sp.	35	1	4	2
plectambonitid, gen. and sp. indet. a	1			
plectambonitid, gen. and sp. indet. b	1			
plectambonitid, gen. and sp. indet. c		6		
<i>Christiania</i> sp.		7		
<i>Rugostrophia latireticulata</i> n. sp.	27			
porambonitid, gen. and sp. indet.		1		
<i>Camerella?</i> sp.	6			
<i>Rhysostrophia?</i> sp.	2			

GSC

accumulated in more turbulent water than the fine-grained richly fossiliferous rock at Virgin Arm.

Specific observations bearing on environmental interpretations are noted below.

#### Virgin Arm

The calcareous tuff at Virgin Arm yielded more than 700 specimens of brachiopods distributed among 27 different species (see table) described in this report and 58 trilobite specimens placed in 11 species by Dean (1974). Its undescribed fossils include bryozoans, gastropods, disarticulated pelmatozoan debris, tabular colonies of an organism resembling the alga *Solenopora*, and fewer orthoconic cephalopods, pelecypods and ostracodes; identification of some of these were made by specialists of the U.S. Geological Survey, as follows:

#### Bryozoans (O. L. Karklins, oral commun., 13 March, 1974):

Crystalline wall structure precludes generic and specific identification; common forms are hemispheric and branching cylindrical trepostomes; bifoliate cryptostomes rare.

#### Gastropod molluscs (E. L. Yochelson, written commun.,

17 January, 1974): ?*Malayaspira* sp., 4 specimens (cf. *Lesueurilla?* sp., Yochelson in Neuman, 1964, p. E24, E25, Pl. 4, figs. 13-17); *Tropidodiscus* sp., 3 specimens; *Mimospira* sp., 2 specimens; *Loxoplocus* (*Lophospira*) sp., 1 specimen; aff. *Cyclonema* sp., 1 specimen. These kinds of gastropods are widely distributed, some in upper Lower Ordovician rocks, and others higher in the Ordovician.

#### Pelecypod molluscs (John Pojeta, Jr., oral commun., 13

March, 1974): 3 specimens, 2 identifiable: *Ctenodontia* sp. and *Deceptrix?* sp.

#### Ostracodes (J. M. Berdan, written commun., 3 January,

1974): 5 specimens, internal moulds that appear to belong to a large species of *Schmidtella* similar to one in the Kanosh Shale of the Pogonip Group in Utah.

These fossils and the rock that contains them suggest unusual conditions of environment and sedimentation. Faunal abundance and diversity indicate a highly productive environment in warm water, and the colonies of probably algal origin suggest growth within the euphotic zone in water no more than 80 m deep. In its most calcareous parts about 20 per cent of the rock is carbonate; although the source of all this carbonate cannot be identified, much is disarticulated pelmatozoan debris, and all is presumably of organic origin. Tectonic fragmentation aside, most brachiopod shells are whole, outlines appear to be complete, fine details are well preserved, and no specimens preserve borings such as those seen on some specimens from Village Cove and Fairbanks East. Most trilobites and brachiopods are disarticulated but very small brachiopods and larger ones of concavoconvex or convexonconcave profile commonly are articulated. These features suggest that the bottom sediments

of fine volcanic ash were exceptionally soft and that brachiopod shells were buried shortly after the death of the animals. Such sediment may well have pressed concave shells into their convex counterparts, while offering little resistance to dissociation of those of opposite convexity. The absence of borings also indicates that the shells were buried before the boring organism could become established.

#### *Village Cove*

The fossiliferous tuff at the roadside locality (GSC locality 91672) 0.96 km northwest of Village Cove is very sparingly calcareous, nearly uniform in texture, and lacks conspicuous bedding features. Of the 14 brachiopods identified from here eight occur in the Virgin Arm assemblage and six of these eight also occur elsewhere in related rocks; the six others, including the important genera *Eodalmanella* and *Christiania*, are known only here. Other phyla, such as trilobites, bryozoans and pelmatozoan debris, abundant in the Virgin Arm rocks, are less common here and no molluscs or calcareous algae were seen.

The brachiopods from this locality were re-examined in the light of information obtained from the Virgin Arm assemblage, and some earlier identifications (Neuman, 1968, p. 37) have been revised (see table, col. B). Accordingly, specimens formerly identified as *Valcourea* sp. (Neuman, 1968, Pl. 3-1, figs. 3a, 3b) are found to belong to *Ahtiella paucirugosa* n. sp.; some specimens identified as *Orthambonites* sp. prove to belong to *Plectorthis* sp.; and specimens identified as *Eoplectodonta* sp. and *Porambonites* sp. are no longer identified as to genus and are here referred to as plectambonitid, gen. and sp. indet. *c* and porambonitid, gen. and sp. indet., respectively.

The few brachiopod shells that are articulated include those with biconvex and those with convex-concave profiles. Some disarticulated shells are grooved by long borings of an unknown organism. These borings are subcircular in cross-section, about 1 mm in diameter, 1 cm or more long, parallel to the shell surface, commonly intersecting or intruding upon either the inner or outer surface of the shell. The borings thus probably were made after the death of the brachiopods and disarticulation of their shells.

These observations suggest that the fossiliferous rocks at the Village Cove locality accumulated in water much deeper than that of the more calcareous rocks at the Virgin Arm locality, where faunas are considerably more abundant and diverse. Differences in occurrence of articulation between the Village Cove and Virgin Arm localities, and the borings in Village Cove specimens suggest that the tuffaceous bottom sediments at Village Cove were firmer than at Virgin Arm. This difference in cohesiveness may have assisted in keeping some shells together while supporting other shells at or near the sediment-water interface within the habitat-range of the boring organism.

#### *Fairbanks East*

*West Beach.* Preparation of fossils from samples of volcanoclastic sandstone from this locality (GSC locality 92035) is still incomplete. Nevertheless, *Productorthis* already appears to be by far its most abundant brachiopod. Many

specimens of the *Productorthis* are articulated, as are those of the small plectambonitid, and the long thin growth lamellae are well preserved. A few fragments of the *Solenopora*-like organism are present, but trilobites, bryozoans, pelmatozoan debris and other phyla are rare. No borings were found on the brachiopod shells.

This assemblage in a fine-grained, well bedded rock, apparently winnowed of its finest grained components, may represent deposition within the euphotic zone in water depth near that at Virgin Arm, but the water here was more turbulent than that at Virgin Arm.

*Main cove.* Large specimens of several different gastropod genera and of orthoconic and coiled nautiloid cephalopods are more abundant than brachiopods in the coarse-grained pebbly sandstone of this locality (GSC locality 92036). Fragmentary trilobites include *Annamitella?* sp. and an undetermined species and genus each of a harpid and an encrinurid (W.T. Dean, *written commun.*, April 1, 1974). Bryozoans and pelmatozoan debris are also common. All brachiopod specimens are disarticulated, many are fragmentary and some are riddled with borings. The poorly sorted, obscurely bedded rock containing these fossils consists of rounded red sand- to pebble-size volcanic rock. Such material was probably derived from a subaerially weathering volcanic terrane. The fossiliferous rock, therefore, represents nearshore deposition in shallow turbulent water.

## Age and Geographic Significance of the Brachiopods

The brachiopod assemblage from Virgin Arm and related localities in the Summerford Group is remarkable not only for its abundance and diversity but for the number of hitherto unknown genera and for the association of known genera not previously found together. Smaller assemblages of this kind were reported (Neuman, 1964, 1968, 1971) from presumably coeval tuffaceous rocks in Maine and in New Brunswick. The combination in a volcanic environment of novel (*i.e.*, endemic) genera together with genera hitherto known from different faunal provinces, different segments of Ordovician time, or both, led to my suggestion (Neuman, 1972, p. 300) that they represent accumulations around islands in the Proto-Atlantic Ocean and that these islands were the sources of stocks that from time to time became established on the continental platforms and margins.

This assemblage of fossils is most probably late Arenig or early Llanvirn and the late Arenig assemblage at Anglesey, northwestern Wales (Bates, 1968) is the most closely comparable.

Brachiopods, trilobites and probably other benthonic fossils of the early half of the Ordovician are highly provincial. Three principal faunal provinces have been identified in the North Atlantic region from independent work on brachiopods and trilobites (Williams, 1969, 1973; Whittington and Hughes, 1972). Although Williams's brachiopod provinces have names different from the trilobite provinces

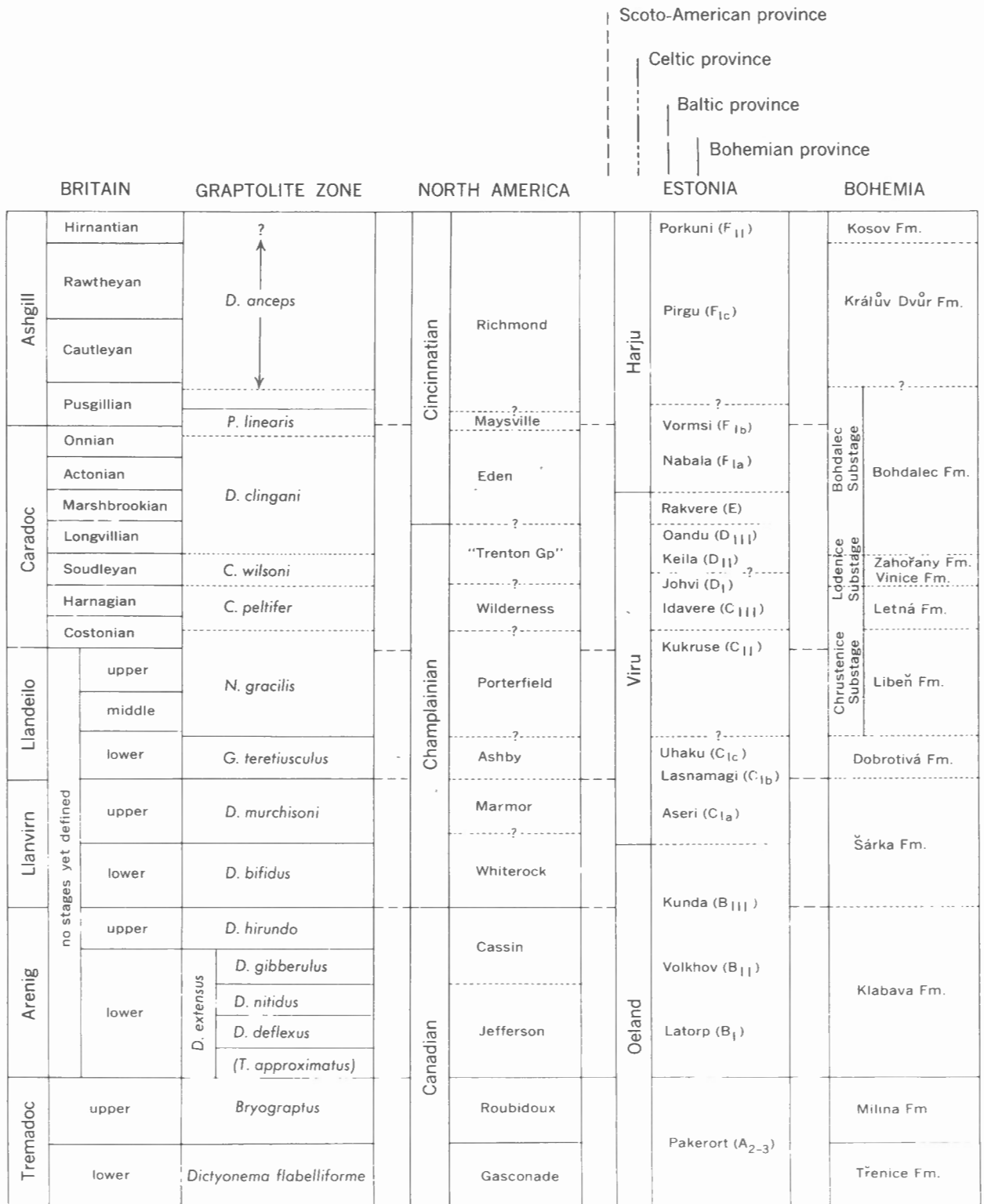


Figure 1. Ranges of brachiopod genera that occur in provinces bordering the Proto-Atlantic Ocean and at Virgin Arm and Village Cove, Newfoundland. The 14 genera to the left of the double-ruled vertical line occur at the Virgin Arm locality; the 5 of those marked + and the 3 to the right of the double line occur at the Village Cove locality. Correlation chart slightly modified and rearranged from Williams, *et al.* (1972, Fig. 2). Provinces after Williams (1973): Scoto-American includes both Northwestern American and Scoto-Appalachian; Celtic

Orthisocrania																				
Orthambonites +																				
Productorthis +																				
Glypteria																				
Plectorthis +																				
Paurorthis																				
Atelelasma																				
Tritoechia +																				
Antigonambonites																				
Progonambonites																				
Ingria																				
Ahtiella +																				
Inversella																				
Rugostrophia																				
Multispinula																				
Eodalmanella																				
Christiania																				

Sources 5,9,15 2,4,12\* 2,12\* 1,2 2,11 2,3,4,7,9\* 2\* 1,4,14 2,9 9 3,7 2,7 8,10 6\* 2 4 10,13

and Baltic unchanged from Williams; Bohemian in lieu of Anglo-French in the absence of published data on the latter. Sources: 1. Bates (1968); 2. Cooper (1956); 3. Havlíček (1971); 4. Havlíček and Vaněk (1966); 5. Huene (1899); 6. Neuman (1971); 7 to 9. Öpik (1932, 1933, 1934); 10. Rõõmusoks (1970); 11. Ross (1970); 12. Rubel (1961); 13. Spjeldnaes (1957a); 14. Ulrich and Cooper (1938); 15. Wright (1970); asterisk indicates generic identifications of Anglesey fossils by Neuman and Bates.

of Whittington and Hughes, they centre around the same geographic areas and compare as follows:

<i>Brachiopod provinces</i> (Williams, 1969, 1973)	<i>Trilobite provinces</i> (Whittington and Hughes, 1972)
Baltic province	Asaphid province
Scoto-Appalachian province (includes northwestern American province)	Bathyrud province
Anglo-French (?=Bohe- mian) province	Selenopeltis province

The Celtic province of Williams (1973, p. 249), which includes Anglesey and southeastern Ireland, and whose brachiopods most closely correspond to those under discussion here, was not recognized by Whittington and Hughes, although they (p. 270) discussed anomalies presented by both the Anglesey and southeastern Ireland occurrences and the closely related fossils from northern Maine.

The ranges and occurrences in these provinces of the 14 genera of brachiopods previously described that occur at Virgin Arm are plotted on Figure 1. The correlations used for this chart follow Williams (*in Williams, et al., 1972, Fig. 2*). Upper Arenig and lower Llanvirn rocks on Anglesey (Bates, 1968; Neuman, 1972; Neuman and Bates, *unpubl. data*) contain nine of these genera—*Orthambonites*, *Productorthis*, *Glypterina*, *Paurorthis*, *Tritoechia*, *Atelelasma*, *Antigonambonites*, *Ahtiella* and *Rugostrophia*. Of these, *Paurorthis*, *Tritoechia*, *Antigonambonites* and *Rugostrophia* occur only in upper Arenig equivalents in this sequence; *Atelelasma* only in the lower Llanvirn equivalent; *Productorthis* and *Ahtiella* in upper Arenig and lower Llanvirn equivalents; and *Orthambonites* from the lower Arenig into the Caradoc parts.

Nine of the 14 Virgin Arm genera have been recorded in the Baltic province. Of these, *Productorthis* and *Ingria* are in upper Arenig and lower Llanvirn equivalents; *Paurorthis* and *Antigonambonites* range from lower Arenig through lower Llanvirn equivalents; *Progonambonites*, *Ahtiella* and *Inversella* are in Llanvirn equivalents only; *Orthambonites* ranges from upper Arenig through Llandeilo equivalents; and *Orthisocrania* is known only from upper Llandeilo equivalents.

Four of the Virgin Arm genera are not known in the Baltic region but occur at different levels in the Scoto-Appalachian province. *Tritoechia* has been found in rocks no younger than Arenig (Canadian) age; *Plectorthis* in lower Llanvirn (Whiterock) and younger Middle Ordovician rocks; and *Glypterina* and *Atelelasma* in Llanvirn (Marmor) and younger Middle Ordovician rocks. Three of these occur on Anglesey: *Tritoechia* in upper Arenig equivalents, and *Glypterina* and *Atelelasma* in the lower Llanvirn.

Of the Virgin Arm brachiopods assigned with less confidence to described genera, one (*Platystrophia*) has been reported from the Baltic upper Arenig; it occurs in the lower Llanvirn of Anglesey (Neuman, 1972, p. 299). (The shell surface of the Virgin Arm specimens is smooth, like that of the specimens from the Shin Brook Formation, Maine (Neuman, 1964, p. E17); details of the shell surface of older

Baltic and Anglesey *Platystrophia* are not preserved or have not been described, whereas granulose shell surfaces have been described or can be seen on most Caradocian and younger species of the genus.) Four of the questionable generic assignments are for genera that are exclusively Scoto-Appalachian: *Taffia* and *Rhysostrophia* of Whiterock (early Llanvirn) age; *Camerella* ranging through almost the entire Ordovician; and *Bimuria*, which is not recorded in this province or elsewhere earlier than late Llandeilo (Porterfield).

Three additional genera from the Village Cove locality should be considered in assessing the significance of this assemblage: *Multispinula*, *Eodalmanella* and *Christiania*. *Multispinula* is a Scoto-Appalachian genus of late Llandeilo to early Caradoc age; *Christiania*, a long-ranging and wide-spread Ordovician genus, first appeared elsewhere in late Llanvirn Baltic rocks but is not recorded from the Scoto-Appalachian province in rocks beneath probably upper Llandeilo equivalents. *Eodalmanella*, by contrast, has hitherto been found only in Llanvirn rocks in the Bohemian province.

The six new genera described in this paper belong to suprageneric taxa comparable to the established genera in age and distribution. Two (*Jaanussonites* of the Gonambonitinae and *Guttasella* of the Ahtiellinae) belong to subfamilies known from Baltic and Anglesey genera; one (*Virgoria* of the Paurorthidae) belongs to a family represented in rocks of this age only in the Baltic province and on Anglesey; one (*Acanthorthis* of the Plectorthidae) belongs to a family present in the Baltic and Scoto-Appalachian provinces as well as on Anglesey; and two (*Calypsolepta* of the Leptellininae and *Anechophragma* of the Leptestiinae) belong to subfamilies whose early genera were known heretofore only in the Scoto-Appalachian province.

In summary, the similarity of the Virgin Arm brachiopod assemblage to that of the coeval rocks of Anglesey and southeastern Ireland in the association of Baltic, Scoto-Appalachian and endemic genera, including many in common, suggests the close relationship of the two assemblages. The Anglesey and Irish rocks, constituting the Celtic province of Williams (1973, p. 249), were interpreted as deposits on the flanks of the Irish Sea uplift (Williams, 1969, p. 260), an island exposing Precambrian sedimentary rocks (Bates, 1972, p. 32). The Summerford Group, which includes the Virgin Arm and Village Cove fossiliferous rocks, was interpreted as a volcanic island complex (Horne, 1970, p. 1782, 1783), as were the related fossiliferous rocks in Maine and New Brunswick (Neuman, 1968, p. 40). It seems reasonable, therefore, to enlarge the concept of the Celtic province to include both regions.

Oceanic islands are important in both structural and biological aspects of geological history. Islands of volcanic composition are essential elements of the plate-tectonic mechanism and form along rifting zones and subduction zones. Islands and submerged remnants of continental materials occur in present as well as past ocean basins and are incidental to plate-tectonic mechanisms. Present oceanic islands play special roles in biological evolution, as habitats for migration of shallow marine benthonic organisms (and terrestrial organisms as well) between continents, and as sites of relatively isolated endemic evolution (Thomson, 1918,

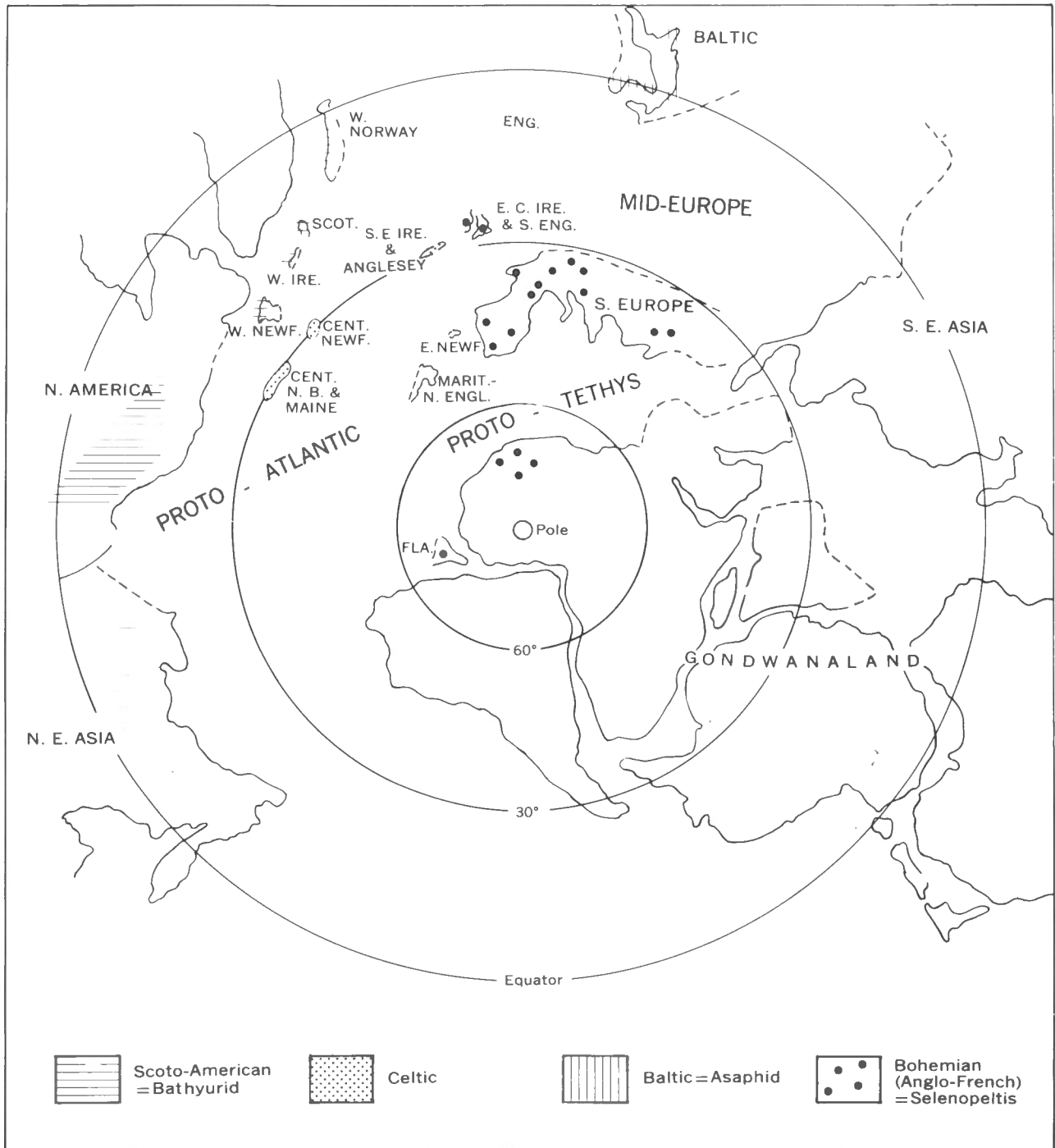


Figure 2. Paleogeographic reconstruction showing brachiopod faunal provinces of the proto-Atlantic region. Adapted from the Southern Hemisphere map of Arenig-Llanvirn time 'concocted' by Whittington and Hughes (1972, Fig. 3B). Abbreviations for geographic areas: *Scoto-American province*—W. Norway, western Norway; Scot., Scotland; W. Ire., western Ireland; W. Newf., western Newfoundland. *Celtic province*—

S.E. Ire. & Anglesey, southeastern Ireland and Anglesey; Cent. Newf., central Newfoundland; Cent. N.B. & Maine, central New Brunswick and central Maine. *Anglo-French province*—E.C. Ire. & S. Eng., east-central Ireland and southern England; E. Newf., eastern Newfoundland; Marit.-N. Engl., parts of the Maritime Provinces of Canada, southern Maine, and eastern Massachusetts; Fla., Florida.



p. 46–61; MacArthur and Wilson, 1967; Valentine, 1971, p. 255, 259).

Most recent portrayals of Ordovician paleogeography accept plate tectonics. In these reconstructions, the Eurasian and North American continental blocks are separated by a Proto-Atlantic Ocean but its width and configuration can only be guessed at and the location of islands within it is equally uncertain. The paleogeographic maps of Whittington and Hughes (1972, p. 246, 247) are reasonable reconstructions, and the areas constituting both the Anglesey-Irish and North American elements of the Celtic province can be plotted on them in midocean (Fig. 2). Whether the Summerford Group and related rocks in North America in such a position represent a midocean ridge, consistent with the reconstruction of pre-Taconian continental and oceanic elements by Bird and Dewey (1970, p. 1043, Fig. 7a), or were parts of an island arc as suggested by Horne (1970, p. 1783), cannot be determined without additional geological and paleontological information.

The many genera newly encountered along with established genera in this province imply an ancient shallow-water habitat surrounding islands, as these genera may have evolved independently from those that evolved in continental waters. The few older occurrences of fossils on and near New World Island suggest that this habitat is at least as old as Tremadocian. Lower Arenig fossiliferous limestone interbedded with volcanic rocks of the Lushes Bight Group, 60 miles west of New World Island, yielded a small but somewhat anomalous assemblage of trilobites (Dean, 1970) and a single brachiopod genus (Boucot, 1973). Tremadoc (Gasconade) trilobites and cephalopods whose identifications have not yet been published were found in the lower volcanic unit of the Summerford Group on New World Island (Horne, 1970, p. 1771). Middle Cambrian limestone with trilobites also occurs in the vicinity but its original setting has not been determined; the rock was found as a boulder in the Middle Ordovician Dunnage Formation (Kay and Eldredge, 1968).

## Paleontology

The calcareous tuff from the Virgin Arm locality is very fine grained and manifestly deformed. Although a few specimens of fossils are visible on freshly broken surfaces, decalcification reveals many more, and the entire sample was alternately broken and etched in hydrochloric acid to obtain the most internal and external moulds of brachiopods.

Textural variation within the rock was brought out by this treatment, which showed, in addition to the alternation of more and less calcareous layers, common tabular colonies as much as 2 cm thick of probably algal origin. The more calcareous layers, which are soft and friable after decalcification, contain the smaller specimens of brachiopods; larger specimens are better preserved where the rock is less calcareous, but occur in both.

The rock has a tectonic deformation fabric. Virtually all fossils are deformed and many are broken by small faults and fractures. Deformation of brachiopods limits their classification. Brachiopod species commonly are discriminated by characteristics of dimension and proportion, especially those that determine various aspects of shape and shell sculpture. These characteristics of the original shells were distorted by tectonic deformation. A category of 'metamorphic species' for distorted fossils of this kind was proposed long ago by H.S. Williams (1917, p. 52), who suggested names from classical mythology. His proposal found no adherents and the problem of taxonomy of deformed fossils at the species level remains. The solution in the present work is to give specific identifications only for those forms whose diagnostic features can be stated as present or absent. The six new monotypic genera described here each required the erection of a new species, but these species will probably be much less useful in the future than the genera based on them.

The brachiopods preserve some features remarkably well. Internal features of the cardinalia, articulating apparatus and muscle scars are preserved as impressions or internal moulds. Rubber replicas of interiors and exteriors of the fossils were made of both valves wherever the hardened mould was strong enough. A sculptor's separating solution aided in separating the rubber replica from relatively weak rock.

Very small features are also preserved, most notably the transition from exopunctae to true punctation in *Plectorthis*, and the rows of punctae in *Paurorthis*, seen as fine threads of matrix that remain after solution of the calcite shell. Similar external details are preserved, such as the filling of hollow costellae of the new genus *Jaanussonites*, the long growth lamellae of *Productorthis* and the impressions of spines of the new genus *Acanthorthis*.

The relative abundance of specimens among the brachiopods is indicated by the number of specimens studied of each taxon. The total counts of specimens among the rarer forms range from one to 83; additional specimens of the more common forms that were not included in the counts are on pieces of rock that have more than one specimen or were destroyed in the process of preparing the less common forms. In addition to the classified specimens included in these counts are many too poorly preserved to be identified.

All figured and measured specimens have been accessioned by the Geological Survey of Canada, Ottawa, and have been assigned GSC numbers. If specimens were abundant, representative ones were given to the U.S. National Museum of Natural History, Washington, D.C.

Photographs were taken by R. H. McKinney of the U.S. Geological Survey. Most internal and external moulds were blackened by brush, and they and the rubber replicas were dusted with ammonium chloride immediately before photography. Photographs of internal and external moulds were trimmed to preserve matrix adjacent to specimens; those of rubber replicas were trimmed to the edges of specimens.

## Systematic Descriptions

Phylum BRACHIOPODA Dumeril, 1806

Class INARTICULATA Huxley, 1869

Order ACROTRETIDA Kuhn, 1949

Suborder CRANIDINA Waagen, 1885

Superfamily CRANIACEA Menke, 1828

Family CRANIIDAE Menke, 1828

Genus *Orthisocrania* Rowell, 1963*Orthisocrania* sp.

Pl. 1, figs. 1, 2

One dorsal valve (GSC 34958) is positively assigned to this genus, and four specimens are assigned to it questionably. Internal moulds are finely pustulose, reflecting the punctate structure of the shell. The dorsal valve is 13 mm wide and 11 mm long. The muscle fields are not well preserved on the internal mould but a moderately high and narrow median ridge runs through its posterior half, flanked by well impressed pinnate mantle canals. The radial ornament characteristic of the genus is preserved on the fragment of the corresponding external mould, and there are about 10 costellae per 5 mm at the anterior margin.

*O. planissima* (Eichwald) from rocks as old as Llanvirn on the Russian Platform is the oldest species of this genus. Specimens from Estonia (C. Schuchert, collector) in the U.S. National Museum (labelled "Kuckers (Brandschiefer) . . . near Jewe") that probably belong to this species have about 15 costellae per 5 mm, as do other specimens of it from the Russian Platform illustrated by Alikhova (*in* Alikhova, *et al.*, 1954, Pl. 8) and in the Russian "Osnovy" (Goryanskii *in* Sarycheva, ed., 1960, Pl. 3. *See also* Huene, 1899, Pl. 2, figs. 3–8). There are about 10 costellae per 5 mm on the specimen of the British species. *O. divaricata* (McCoy), of probably Caradoc age (Wright, 1970) illustrated by Rowell (*in* Williams, *et al.*, 1965, Fig. 181–6). In ornament, therefore, the Newfoundland specimen is more like the younger British species than the older Baltic form.

*Measurements, Orthambonites*

GSC no.	Length	Width		Costae
		hinge	max.	
34959	19.5	22.4	30.5	20
34960	18.0	26.5	29.0	—
34961	17.0	32.0	32.0	21
34962	22.0	15.5 (34)	28.0	—
34964	26.0	25.0 (28)	(28)	—

( ) Estimate.

Class ARTICULATA Huxley, 1869

Order ORTHIDA Schuchert and Cooper, 1932

Suborder ORTHIDINA Schuchert and Cooper, 1932

Superfamily ORTHACEA Woodward, 1852

Family ORTHIDAE Woodward, 1852

Subfamily ORTHINAE Woodward, 1852

Genus *Orthambonites* Pander, 1830*Orthambonites* sp.

Pl. 1, figs. 13–22

The 60 large specimens of this genus from Virgin Arm have coarse costae that suggest their affinities with species from the early half of the Ordovician.

*Description.* Large ventribiconvex shells, elliptical in outline, wider than long, cardinal angles obtuse, maximum width at about one-third shell length. Ventral interarea short, apsacline; dorsal interarea anacline, about half the length of that of ventral valve. Delthyrium and notothyrium open, unmodified. Lateral profile broadly arched. Dorsal valve has shallow broad sulcus, ventral valve correspondingly arched; anterior commissure gently sulcate. Ornament of about 20 unbranched rounded striated costae; growth lines crowded in interspaces. Costae impressed on inner surface of valves.

Dorsal interior has low short notothyrial platform, thickened anteriorly. Cardinal process thin, bladefike, with bulbous anterior expansion on larger specimens. Brachio-phores short, triangular in cross-section; sockets shallow. Median ridge low, broad, confined to posterior third. Adductor muscle scars and vascular system not preserved.

Ventral interior has short stout teeth; dental plates thick, advancing. Pedicle callist present. Adductor track wide, slightly longer than diductors and thicker anteriorly. Vascular system not preserved.

*Discussion.* Large, coarse-ribbed *Orthambonites* in the earlier Ordovician include such species as *O. proava* (Salter) in Wales (Bates, 1968, p. 146, 147, Pl. 2, figs. 1–8) and *O. robustus* Neuman (1964, p. E13–E15, Pl. 1, figs. 1–13) in Maine, both of Arenig age; *O. tiffletensis* Havlíček (1971, p. 30, 31, Pl. 2, figs. 14–23) of Llanvirn or Llandeilo age; and *O. neumani* Cooper (1956, p. 307, 308, Pl. 37, figs. 19–35), probably Caradoc. Several small similar species have also been described from throughout the Ordovician. Earlier species generally have fewer costae than later ones. Other criteria for specific discrimination rest with details of proportion, features that cannot be determined from the deformed specimens under discussion here.

*Occurrence.* In addition to the Virgin Arm specimens described here, a few identical specimens were obtained from the Village Cove locality, some as short as 6 mm, and from the Fairbanks East localities.

The large specimens reported from the Shin Brook Formation of Maine (Neuman, 1964, p. E14, E15) probably also belong to this species.

#### Subfamily PRODUCTORTHINA Schuchert and Cooper, 1932

##### Genus *Productorthis* Kozłowski, 1927

##### *Productorthis mainensis* Neuman, 1964

Pl. 1, figs. 3–12

*Productorthis mainensis* Neuman, 1964, p. E15, E16, Pl. 2, figs. 1–11; 1968, Pl. 3-1, figs. 1a–g

Among the 68 Virgin Arm specimens assigned to this species are several that are better preserved than those previously illustrated from Maine and from the Village Cove locality. Details of the contrasting ornament of the opposite valves can be observed: the dorsal valve is notably frilly but radial ornament is suppressed, whereas the ventral valve has a more pronounced radial ornament but suppressed frills (Neuman, 1964, p. E15). Growth lamellae across the anterior parts of both valves are 1.5 to 2 mm long; those of the nearly flat (and consequently shorter) dorsal valves are imbricated so that there is about 75 per cent overlap, but in the highly convex (and longer) ventral valve growth, overlap is only about 25 per cent. The species is also abundant at the west beach of Fairbanks East.

#### Family DOLERORTHIDAE Öpik, 1934

##### Subfamily GLYPTORTHINAE Schuchert and Cooper, 1931

##### Genus *Glypteria* Boucot, 1970

##### *Glypteria* sp.

Plate 2, figs. 1–8

Thirty-eight small specimens, including 10 articulated internal moulds, belong to this genus.

*Description.* Small, highly ventribiconvex, elliptical outline, wider than long, cardinal angles obtuse, widest at about one-third shell length, greater than hinge width. Ventral interarea long, apsacline; delthyrium narrow, open; dorsal interarea short, orthocline, about one-quarter the length of that of ventral interarea; notothyrium open. Ventral valve pyramidal, with uniform curvature in lateral profile from erect beak to anterior margin; dorsal valve gently arched, shorter than ventral valve. Dorsal valve has low sulcus in posterior half, occupied by two costae and a median interspace; sulcus not persistent anteriorly. Ventral fold low, accentuated

by unbranched median costa. Anterior commissure straight. Radial ornament coarsely costate (none bifurcated), generally 13 or 14 costae; concentric ornament of growth lamellae, about 6 per mm in the central sector of the anterior third of ventral valves, somewhat more closely spaced on dorsal valves.

Dorsal interior has deep notothyrial cavity; cardinal process simple, thickened at base; brachiophores stout, lathlike, erect; sockets elevated, bounded by low fulcral plates. Median ridge low, broad, confined to posterior half of shell floor between adductor muscles, beyond which it merges with internal impression of median interspace. Adductor muscle field extends nearly to midlength of shell floor; muscle scars elliptical, anterior pair larger than posterior pair. Vascular system not preserved. Radial ornament impressed into anterolateral third of valve.

Ventral interior has deep delthyrial cavity with small pedicle callist at apex. Teeth stout, dental plates short, receding. Muscle field short, about 0.75 mm in valves 3 mm long. Adductors poorly differentiated from diductors, extending a bit beyond them at slightly thickened anterior margin. Vascular system not preserved. Radial ornament impressed as on dorsal valve.

#### *Measurements*

GSC no.	Length	Width		Costae
		hinge (mm)	max.	
34971	3.5	3.0	4.0	14
34972	2.0	3.0	3.5	13

*Discussion.* This species remains unnamed because of poor preservation. It has fewer costellae than other early species of *Glypteria* that have been described (Boucot, 1970). *G. kleinhamplei* (Ross) from the Antelope Valley Limestone, Nevada has 18 or 19 (Ross, 1967, p. D4); *G. lamellosa* (Raymond) from the Valcour Formation, New York has 18 (Cooper, 1956, Pl. 42, fig. 12); and *G. glypta* (Cooper) from the Lenoir Limestone, Tennessee has 17 (Cooper, 1956, p. 386). In this respect the species is most like the younger *G. uniplicata* (Cooper) from the Benbolt Formation, Virginia of Cooper and Prouty (1943), which has about 13 costae.

#### Family PLECTORTHIDAE Schuchert and LeVene, 1929

##### Subfamily PLECTORTHINAE Schuchert and LeVene, 1929

##### Genus *Plectorthis* Hall and Clarke, 1892

##### *Plectorthis* sp.

Pl. 2, figs. 13–21

The 38 specimens from Virgin Arm assigned to this genus include some small ones that are presumably juveniles and some that are exceptionally large for the genus. All are

notable for the preservation of closely spaced pairs of fine pits (exopunctae) on the shoulders of the costae throughout their length, some of which near the anterolateral margins traverse the shell and are endopunctae.

*Description.* Ventribiconvex, of wide size range, rounded outline, somewhat wider than long; cardinal angles slightly obtuse, widest at about one-quarter shell length, slightly greater than hinge width. Ventral interarea short, apsacline, delthyrium open. Dorsal interarea anacline, about one-third the length of ventral interarea; notothyrium open. Lateral and anterior profiles lenticular; dorsal valve gently and uniformly arched; ventral valve more highly arched, about twice as high as dorsal valve. Lateral and anterior commissures straight. About 20 costae, rounded, slightly narrower than interspaces; sides of costae finely striated. Growth lamellae fine, closely spaced, in interspaces and on flanks of costae. Pairs of exopunctae on shoulders of costae, seen as fine spiculelike spikes of matrix, 2 to 4 per mm, perpendicular to shell curvature viewed from anterolateral margins, and projecting posteriorly from interior of shell towards the exterior at about 45°; most taper to a point a short distance from shell interior, but around the anterolateral margins of some specimens threads of matrix (punctae filling) are uninterrupted between internal and external surfaces (Pl. 2, fig. 18), and in this region of other specimens spiculelike spikes project from internal surfaces.

Dorsal interior has low notothyrial platform bearing simple bladlike cardinal process. Brachiophores subtriangular in cross-section, tapering to a point, divergent. Sockets elevated, bordered by low fulcral plates. Median ridge low, confined to posterior half of valve. Adductor muscle field weakly impressed, only the posterior pair preserved as small triangular calluses. Vascular system not preserved. Ornament impressed well into valve around anterolateral margins, each costa bearing a median groove.

Ventral interior has deep delthyrial cavity bordered by short vertical dental plates that join the thickened lateral margins of the muscle field. Teeth not observed. Pedicle callist short, thick. Adductor muscle track not clearly differentiated from diductors. Anterior margin of muscle medially extended, slightly thickened. *Vascula media* weakly impressed. Internal impression of ornament as on dorsal valve.

*Measurements*

GSC no.	Length	Width		Costae	Pits (/mm)
		hinge (mm)	max.		
34975	10.5	12.5 (13.5)	13.5	19	3 to 4
34977	10.0	11.0	13.0	—	3 to 4
34978	7.0	8.0	7.0 (10)	—	—
34979	9.5 (10)	10.5	12.0	—	—
34980	12.0	14.0	16.0	—	—

( ) Estimate.

*Discussion.* *Plectorthis punctata* Cooper (1956, p. 452, Pl. 84, figs. 19–23, 33–35) from the Tulip Creek Formation in Oklahoma (?Llandeilo) was distinguished by its characteristic rows of pits on each side of its costae, like those of

these Virgin Arm specimens. *P. punctata* may be discriminated from these because its valves are folded, it has more costae (some branched) and it is smaller.

Although most of the pits are exopunctae, those around the anterolateral margins are endopunctae. This punctuation is of the kind indicated by Williams and Rowell (*in Williams, et al., 1965, p. H68*), which formed from the accommodation of impersistent caeca rather than from the development of hollow costae. In these specimens, therefore, it can be seen that punctuation is not an 'all-or-none' characteristic (Rudwick, 1970, p. 44).

Subfamily PLATYSTROPHIINAE Schuchert and LeVene, 1929

Genus *Platystrophia* King, 1850

*Platystrophia?* sp.

Pl. 2, figs. 9–12

Seven specimens from Virgin Arm have all the characteristics of *Platystrophia* except that their external surfaces lack the 'granules' that are common throughout the genus.

*Description.* Moderately large, inflated, dorsibiconvex, wider than long, hinge width relatively short, maximum width at about midlength. Lateral profile inflated, interareas long, concave, beaks high. Dorsal valve bears prominent fold, ventral valve has correspondingly deep sulcus; anterior commissure uniplicate. Radial ornament of sharp-crested, V-shaped costae, 3 on the dorsal fold, 4 on the ventral sulcus, 6 or 7 on each flank. Surface covered with fine growth lamellae but lacks granules.

Dorsal interior has deep notothyrial cavity bearing thin bladlike cardinal process; brachiophores stout, on thick supporting plates, elliptical in cross-section at the base, becoming lathlike distally. Sockets elevated, bordered by fulcral plates. Median ridge low, short, sharp-crested. Adductor musculature quadripartite; posterior pair on thickened anteriorly tapering shell callus, smaller than weakly impressed posterior pair. Mantle canal system not preserved. Ornament impressed throughout shell length.

Ventral interior has stout teeth, erect advancing dental plates that merge with thickened margin of elevated muscle field. Anterior margin of muscle field much thickened (pseudospondylium), medially extended. Adductor muscle tracks well differentiated from diductors, set above them on thickened shell, with thin median ridge in posterior half. Diductors narrow, in grooves bordering adductors. Mantle canal system not preserved. Ornament impressed as on dorsal valve.

*Measurements*

GSC no.	Length		Width		Costae	
	total c	interarea	hinge (mm)	max. c	fold or sulcus	flanks
34981	13	1.0	13 (14)	16.5	3	6 or 7
34983	16	—	13	20.0	—	—
34982	17	2.5	12	16.0	4	6 or 7
34984	9 (10)	—	13	15.0	4	6

( ) Estimate. c Circumference.

*Discussion.* Identification of these specimens as *Platystrophia* is questioned because they do not have the granulose, pustulose or spinose external surfaces long noted as characteristic of the genus (Hall and Clarke, 1892, p. 201).

The surfaces of similar specimens from the Shin Brook Formation, Maine (Neuman, 1964, p. E17) were described as "probably granulose", but those specimens were too imperfectly preserved for certain observation: their identification as *Platystrophia* should also be questioned. The fine texture of the rock preserving the external ornament of the specimens described here preserves a pattern of fine growth lamellae, and if pustules such as those to be expected in *Platystrophia* s.s. are present, they should be observable.

Thin sections and detailed examination of well preserved shells suggest that the granular surface of *Platystrophia* reflects the presence of spines (Richards, 1972, p. 392, Pl. 3, fig. 8, Pl. 5, fig. 5). Granular or spinose surfaces are so characteristic of *Platystrophia* that similar forms having smooth surfaces probably should be put in a different genus. A comprehensive review of *Platystrophia* species to test the utility of such a distinction is, however, beyond the scope of this paper.

#### Genus *Acanthorthis* new genus

*Diagnosis.* Platystrophiinid having spinose costellae.

*Derivation of the name.* Greek *akantha* (thorn) + *orthis*

Type species. *Acanthorthis terreneuensis* new species

*Description.* Shells resembling *Platystrophia* in shape, wider than long, having dorsibiconvex lateral profile, large interareas, a wide and high dorsal fold, and a correspondingly deep ventral sulcus; anterior commissure uniplicate. Ornament costellate to multicostellate, costellae bearing spines.

Dorsal interior plectorthid; notothyrial cavity deep, bearing bladlike cardinal process. Brachiophores stout, subtriangular in cross-section at base, supporting plates short. Sockets elevated, bordered by fulcral plates. Median ridge short, sharp-crested.

Ventral interior has stout teeth, advancing dental plates that project forward on the shell floor to form the thickened margin of the elevated muscle area. Adductor track wide, extends beyond diductors; anterior termination thickened, approaching pseudospondylium.

*Discussion.* This monotypic genus is erected to contain the spinose costellate species, *A. terreneuensis*, described below. It possesses a combination of several features known among the plectorthids but not hitherto found together. It has the internal structure and shape of *Platystrophia*, but its multicostellate ribbing is like that of *Schizophorella* and *Hebertella*, and its spinose surface is unlike that of any previously described plectorthid genus.

#### *Acanthorthis terreneuensis* new species

Pl. 2, figs. 22–28

*Diagnosis.* Deeply biconvex *Acanthorthis* with rounded outline and multicostellate ornament bearing spines on the flanks of costellae.

*Material.* Holotype: ventral valve, internal and external moulds, GSC 34986. Figured paratypes: ventral valve, internal and external moulds, GSC 34988; dorsal valve, internal mould (figured) and fragment of external mould (not figured), GSC 34985; fragment of external mould, valve not known, GSC 34987. Measured paratype: ventral valve, internal and external moulds, GSC 34989. Paratypes not figured or measured: 2 dorsal valves, 2 ventral valves.

*Description.* Subequally biconvex shells, wider than long, hinge width relatively short, widest at about midlength. Cardinal angles obtuse, lateral and anterior margins rounded. Interareas long, concave, ventral more than twice the length of dorsal; beaks high. Dorsal valve bears wide, moderately high fold; ventral valve has corresponding sulcus. Anterior commissure broadly uniplicate. Lateral flanks broadly arched, becoming concave toward posterolateral extremities. Ornament of spinose, lamellose, branching and inserted costellae. Costellae V-shaped, crests rounded, about 10 per 5 mm at the anterior margin of large (>15 mm long) shells, about 16 in sulcus and on fold. Growth lirae closely crowded, especially in interspaces, grading into fine growth lamellae around anterolateral margins. Flanks of costella bear fine spines ranged along growth lamellae and lirae, usually 3 between crest and trough of costellae (between 0.5 and 0.75 mm), 8 to 10 per mm along the length of costella; no spines on crests of costellae nor in troughs of interspaces.

Dorsal interior has moderately deep notothyrial cavity slightly elevated anteriorly, cardinal process simple, blade-like. Brachiophores rounded in cross-section, divergent, supporting plates short. Sockets elevated, bordered by small fulcral plates. Median ridge low, sharp-crested, confined to posterior fourth of shell between muscle scars. Adductor muscle scars quadripartite, anterior pair larger than posterior pair, set in shallow, dished depressions having raised anterolateral margins that taper anteriorly. Mantle canal system not seen. Ornament weakly impressed through anterolateral half of shell.

Ventral interior has stout triangular teeth, short stout divergent dental plates that advance onto the shell floor to form the lateral margins of the muscle field. Adductor track wide, longitudinally striated, with very fine median ridge. Diductors impressed more deeply than adductors and separated from them by pair of prominent ridges. Mantle canal system not preserved. Internal impression of ornament as on dorsal valve.

#### Measurements

GSC no.	Length		Width		Costae in sinus
	total c	interarea	hinge	max. c	
	(mm)				
paratype 34985	14	1.0	12	19	—
holotype 34986	14	—	13 (20)	21 (28)	16
paratype 34988	17	2.0	13	15 (18)	17
paratype 34989	23	2.5	19	30	—

( ) Estimate. c Circumference.

*Discussion.* This species is clearly a spinose multicostellate platystrophiinid, but its spines are more widely spaced than the pustules (presumed spine bases) of *Platystrophia*. No species having such an ornament has been recorded before.

Superfamily ENTELETACEA Waagen, 1884

Family PAURORTHIDAE Öpik, 1933

Genus *Paurorthis* Schuchert and Cooper, 1931

*Paurorthis* sp.

Pl. 2, figs. 38–48

Among the 25 Virgin Arm specimens belonging to this genus are several in which punctae along the crests of costellae are well preserved.

*Description.* Ventribiconvex, large for the genus, rounded outline, slightly wider than long; cardinal angles slightly obtuse, maximum width at about one-third shell length, a little greater than hinge width. Ventral interarea concave, short, apsacline; delthyrium open. Dorsal interarea about half the length of ventral interarea, notothyrium open. Lateral profile lenticular, beaks low, thickest at about one-third shell length, ventral valve about twice as thick as dorsal. Dorsal valve has low shallow sulcus, deepest in posterior third; ventral fold low, inconspicuous; anterior commissure slightly sulcate. Costellae V-shaped, nearly uniform, expanding very gradually, and branching two or three times over shell surface; about 14 per 5 mm at the anterior margins of shells 10 to 12 mm long. Punctae along crests of costellae, about 0.1 mm in diameter, 5 per mm, directed obliquely forward from the shell floor. Concentric ornament of fine growth lamellae confined to anterolateral margin.

Dorsal interior has triangular notothyrial platform bearing low rounded median ridge but no cardinal process. Brachiophore bases short, divergent, subtriangular in cross-section, thickened anteriorly, tapering to a point, and flaring upward. Fulcral plates low, forming elevated socket pad. Median ridge low, extends from thickened anterior edge of notothyrial platform to about midlength of shell. Adductor muscle scars elongate, anterior pair larger and more medially placed than posterior pair. Mantle canal system not seen. Radial ornament impressed around anterolateral margin of shell.

Ventral interior has stout triangular teeth, short receding dental plates. Muscle area thickened, elliptical, confined to delthyrial cavity; pedicle callist present. Adductor track wide, occupying about half the width of muscle area, slightly elevated above diductor scars; anterior terminations slightly raised. Median ridge low, broad, short, length equal to or slightly less than that of muscle area. Mantle canal system not seen. Radial ornament impressed as on dorsal valve.

#### Measurements

GSC no.	Length		Width		Thickness	Costellae
	total	interarea	hinge	max. at length specif.		
			(mm)			(/5 mm)
Dorsal valves						
34990	12.0	1.5	13.0	14 at 4	1.5	14
34991	6.0	—	7.0 (7.5)	9 at 4	1.0	—
34993	10.0	1.0	6.0 (8)	9 (10) at 4	1.5	—
Ventral valves						
34994	10.5	2.5	10.0	11 at 6	—	14
34997	10.0	1.5	9.5	11 at 4	2.0	—

( ) Estimate.

*Discussion.* This species is different from other described species of *Paurorthis* in its nearly uniform costellation and in the presence of a short ventral median ridge. The ornament of *Cyclomyonia* “. . . is more even and not so strongly fasciculate as that of *Paurorthis*” (Cooper, 1956, p. 975); internally, *Cyclomyonia* has a wide thick callosity or ridge anterior to the ventral muscle area. However, the ventral median ridge of this species is thinner and narrower than that of *Cyclomyonia*, and it has the narrow muscle area and receding dental plates of *Paurorthis* rather than the distinctive wide muscle area and strong plates of *Cyclomyonia*.

The unusual preservation of punctation in these specimens permits observations not normally available. Punctae are preserved as very fine threads of matrix between inner and outer shell surfaces (Pl. 2, figs. 38, 39); where internal and external moulds are separated, the punctae are preserved as long spines on the crests of costellae on external moulds (Pl. 2, fig. 48) and as radial rows of very small pustules on internal moulds (not illustrated). Punctation along the costellae of *Paurorthis parva* (Pander) was reported by Kozłowski (1929, p. 53, footnote 2: “seulement le long des côtes”), and their radial disposition on the inner shell surface was shown by Öpik (1933, Pl. 4); Cooper (1956, Pl. 151) also illustrated punctae on the costellae of two species of *Paurorthis*. None of these observations provided information on the orientation of the punctae, which is seen in these specimens to be obliquely outward. By contrast, similarly preserved specimens of younger Ordovician enteletaceans (*Howellites* and *Hirnantia*) have finer punctae that are densely and uniformly distributed over the entire shell surface (excluding the interareas), and are oriented perpendicular to the shell surface.

#### Genus *Virgoria* new genus

*Diagnosis.* Small paurorthis having an elongate elliptical notothyrial platform, long brachiophore bases extended anteromedially, and a dorsal median septum that extends the full length of the shell floor.

Type species. *Virgoria virgensis* new species

*Description.* Small ventribiconvex paurorthis; dorsal valve sulcate. Ornament costellate; shell punctate, with punctae on the crests of costellae.

Dorsal interior has low, anteriorly elongate, elliptical notothyrial platform that bears low ridge or poorly developed bladellike cardinal process. Platform bordered by strong anteromedially convergent plates that are surmounted by brachiophores; fulcral plates present. Median septum rises at anterior margin of platform and extends to anterior margin of shell.

Ventral interior has very short dental plates and suboval muscle field.

*Discussion.* Although this monotypic genus is erected to contain the new species *V. virgensis*, whose features are incompletely known, the elongate-elliptical shape of its notothyrial platform, together with its medially convergent brachiophore plates, set it apart from other known paurorthisids. Its assignment to this family is indicated by its shape and ornament, its radially arranged punctae, the presence of fulcral plates and its primitive cardinal process on the dorsal valve, and the internal features of its ventral valve. *Virgoria* differs from other paurorthisid genera in the elongate elliptical shape of its notothyrial platform with its long medially convergent brachiophore-supporting plates. By contrast, the notothyrial platform of *Paurorthis* is triangular, and its brachiophore-supporting plates are short and divergent. The notothyrial platforms of both *Cyclomyonia* Cooper and *Paurorthisina* Rubel are rhombic, outlined by thickened medially extended anterior margins, and both have short brachiophore-supporting plates.

Elongate brachiophore bases are also present in the Ordovician enteletecean *Pionodema* and related genera. In these genera the plates do not converge as they do in *Virgoria*, and their cordate ventral musculature is quite different from the suboval musculature of the *Paurorthisidae*.

*Virgoria virgensis* new species

Pl. 2, figs. 29–37

*Diagnosis.* Very small *Virgoria*, wider than long, with sharp-troughed dorsal sulcus.

*Material.* Holotype: articulated internal mould, GSC 34998. Figured paratypes: articulated internal moulds, GSC 34999, 35000; ventral internal mould, GSC 35003; dorsal internal mould, GSC 35001; dorsal external mould, GSC 35002. Forty-four paratypes not figured or measured.

*Description.* Very small, ventribiconvex shells, rounded outline, wider than long, widest at or near the hinge, cardinal angles near 90°. Lateral profile high, thickest at about one-third shell length, ventral interarea long, about half shell length, concave, apsacline; beak erect; dorsal interarea anacline, length half or less that of ventral interarea. Deltidium and notothyrium open. Dorsal valve has narrow sharp-troughed sulcus; ventral fold less distinct; anterior commissure sulcate. Radial ornament of about 25 punctate costellae around shell margin; zones of intercalation and branching at midlength and near anterior margin. Punctae ranged along crests of costellae, about 10 per mm. Concentric ornament of fine growth lamellae around shell margins.

Dorsal valve has cardinalia as described for genus. Adductor muscle scars elongate, elliptical, bordered by low ridges, anterior pair more centrally placed than posterior pair. Mantle canal system not seen. Radial ornament impressed around anterolateral margin.

Ventral interior as described for genus; muscle area variably impressed, ranging from specimens having imperceptible anterior margins to those that are thickened; pedicle callist present. Mantle canal system not seen. Radial ornament impressed as on dorsal valve.

*Measurements*

GSC no.	Length		Hinge width	Thickness	Costellae
	total	interarea			
Articulated valves					
paratype					
34999	1.8	—	2.7	1.0	—
holotype					
34998	2.0	—	2.0 (2.5)	0.8	—
paratype					
35000	1.8	—	2.4	0.5	—
Dorsal valves					
paratype					
35001	2.0	—	2.7	—	—
paratype					
35002, e.m.	2.0	—	2.0 (2.4)	—	20 (26)
Ventral valve					
paratype					
35003	2.0	1.0	2.2	—	—

( ) Estimate. e.m. External mould.

*Discussion.* No other species is known to have the characteristics of *V. virgensis*. In addition to its distinctive cardinalia, it is the only paurorthisid having a median septum the full length of the shell. Externally, it is smaller, more carinate and thicker (compared with length or width) than other paurorthisids.

Suborder *CLITAMBONITIDINA* Öpik, 1934

Superfamily *CLITAMBONITACEA* Winchell and Schuchert, 1893

Family *CLITAMBONITIDAE* Winchell and Schuchert, 1893

Genus *Atelelasma* Cooper, 1956

*Atelelasma atlanticus* new species

Pl. 3, figs. 6–23

*Diagnosis.* *Atelelasma* having long imbricated growth lamellae the full length of both valves.

*Material.* Holotype: dorsal valve, internal mould and counterpart external mould, GSC 35004. Figured paratypes: dorsal valves, internal and external mould, GSC 35005, internal mould, GSC 35007, and external mould, GSC 35006; ventral valves, internal and external moulds, GSC 35008, and 2 external moulds, GSC 35009, 35010. Eighty-three paratypes not figured or measured.

*Description.* Moderate-size, highly ventribiconvex shells,

subquadrate in outline, wider than long, widest at hinge, cardinal extremities rounded-acute, sides subparallel to moderately convergent, anterior margin broad, nearly straight. Lateral commissure straight, anterior commissure broadly and moderately sulcate. Ventral valve pyramidal in lateral profile; interarea long, straight, apsacline, as much as a third of shell length horizontally striated; beak erect, uniform slope to anterior margin; delthyrium bordered by very short plates. Dorsal valve moderately convex, beak low, thickest near middle; anacline interarea about one-quarter length of ventral interarea; notothyrium wide, covered by arched chilidium; sulcus broad and low with sharp median trough, shoulders swollen, posterolateral sides concave. Ornament elaborate, consisting of rounded costellae projected onto long thin growth lamellae throughout shell length. Costellae of two orders: most strong ones originate in region of beak, but a few develop from weaker ones in middle; 4 or 5 minor costellae inserted between fully developed major ones; more costellae exist after formation of a strong one, and fewer in early stages of strong ones. Growth lamellae, each 1 to 1.5 mm long, cover entire surface of shell, 10 to 15 lamellae per 5 mm on the anterior third, somewhat farther apart behind.

Dorsal interior has short notothyrial platform bearing thin bladelike cardinal process; brachiophores widely divergent, extended distally to blunt points; edge of socket pad links brachiophore bases with posterior shell wall, resembling fulcral plates. Median ridge wide, high, extends to midlength of shell. Posterior adductor muscle scars smaller than anterior pair, separated from them by weak transverse ridge; anterior pair mitten-shaped, with narrow, thumb-shaped outer lobes and wider inner lobes, both with rounded anterior margins. Mantle canal system not seen. Radial ornament weakly impressed around anterolateral margin on shell floor.

Ventral interior has short teeth; spondylium simplex steep-sided, longer than median septum; the anterior one third to one quarter is unsupported. Base of median septum extended to midlength of shell floor as slightly raised line. Mantle canal system not preserved except for short ridges of *vascula genitalia* in posterior. Radial ornament weakly impressed around anterior edge of shell floor.

#### Measurements

GSC no.	Length		Hinge width	Thickness	Costellae	Lamellae
	total	interarea				
	(mm)				(per 5 mm)	
Dorsal valves						
holotype						
35004	11 (12)	—	13.0 (17)	1	12	13
paratype						
35005	12 (13)	1.5	13.0	2	14	11
paratype						
35006	10	1.0	11.5	2	—	—
Ventral valves						
paratype						
35008	12	5.0	15.0	4	16	9
paratype						
35011	12	6.0	14.0	3	—	—

( ) Estimate.

*Discussion.* *A. atlanticus* differs from other species of the genus in its lamellar ornament resembling the distinctive ornament of *Ladogiella*. This resemblance led to my mis-assigning both this species and specimens from Anglesey to that genus in an earlier paper (Neuman, 1972, p. 299). The Anglesey species, originally identified as *Apomatella* (?) sp. (Bates, 1968, p. 163, Pl. 6, figs. 8–11), is an *Atelelasma*, and external moulds from the Bod Deiniol Formation on Anglesey preserve a lamellose ornament like that of *A. atlanticus*.

*A. perfectum* Cooper, the type species of the genus, resembles *A. atlanticus* in having two orders of costellae and a well developed concentric ornament (see Cooper, 1956, Pl. 126, figs. 41–45), but its interareas are concave and it is not lamellose. Two other species named by Cooper, *A. oklahomense* and *A. platys*, have strong growth fila but are not lamellose; some specimens of *A. multicostratum* (Hudson) in the collections of the U.S. National Museum have imbricated growth lamellae but only around the anterolateral margins of the valves. Decorticated specimens of *A. decorticatedum* Cooper, and *A. nana* Rozman (in Chugavaeva, et al., 1964, p. 134) do not preserve details of ornament that permit comparison with this species.

#### Family POLYTOECHIIDAE Öpik, 1934

#### Genus *Tritoechia* Ulrich and Cooper, 1936

#### *Tritoechia billingsi* Neuman, 1968

Pl. 3, figs. 1–5

*Tritoechia billingsi* Neuman, 1968, p. 38, Pl. 1.3, figs. 2, a–i

The seven dorsal valves among the 22 specimens from Virgin Arm have the chilidium that is the distinctive feature of this species. In one ventral valve the foramen at the apex of the pseudodeltidium is extended in a short tube. None of the Virgin Arm specimens is as large as the largest of those from Village Cove, but some from the main cove of Fairbanks East are larger.

Details of ornament are better preserved in some of these specimens than they are in any from the Village Cove locality. Costellae are rounded in cross-section, equal in width to interspaces; none of the costellae is hollow. Most of the stronger costellae of the anterior half of the shell arise in the posterior half but some are derived from subordinate costellae at about midlength. Intercalation of minor costellae between major ones is variable: the count of minor costellae between major ones in a 10-mm segment of the best preserved specimen (Pl. 3, fig. 5) showed none between 8 pairs, one between 8 others, and two between 3. Concentric ornament consists of about 15 very fine growth lamellae per mm that project as frills on crests of costellae. Stronger growth lamellae, equally expressed on costellae and interspaces, are irregularly spaced 0.5 to 2 mm apart over most of the shell surface but are crowded and imbricated around the anterolateral margin.



*Measurements*

GSC no.	Length			Width		Thick-ness	Costellae
	total	interarea	dorsal ventral	hinge	max.		
Village Cove specimens							
holotype							
23296	19.5	2.0	—	*12.0	*18.5	4	9
paratype							
23298	23.5	—	7	25.0	27.0	7	10
paratype							
23297	*17.0	1.5	10	22.0	—	—	9
Virgin Arm specimens							
35019	11.5	1.5	—	13.5	13.5	2	—
35020	16.0	—	6	16.0	16.0	—	—
35021	12.0	—	7	16.0	18.0	7	10

\*Incomplete preservation.

## Superfamily GONAMBONITACEA Schuchert and Cooper, 1931

## Family GONAMBONITIDAE Schuchert and Cooper, 1931

## Subfamily GONAMBONITINAE Schuchert and Cooper, 1931

Genus *Jaanussonites* new genus

*Diagnosis.* Ventribiconvex to concavoconvex, ramicostellate, having posteriorly confined cardinalia, notothyrial platform with simple cardinal process but without subsidiary ridges and a wide subperipheral rim in the dorsal valve; in the ventral valve spondylium elevated, supported by a strong median septum that extends considerably beyond it, and thinner and shorter lateral septa.

*Derivation of the name.* For Dr. Valdar Jaanusson

Type species. *Jaanussonites hornei* new species

Species assigned. “*Polytoechia?* sp.” Neuman, 1964, p. E22, E23, Pl. 1, figs. 14–17

*Description.* Medium to large shells, variable in lateral profile, from ventribiconvex to slightly concavoconvex, widest at hinge. Ventral valve apically extended, with long apsacline interarea; delthyrium covered by pseudodeltidium; subapical foramen large, elliptical. Dorsal interarea short, hypercline to anacline; notothyrium wide, covered by chilidium. Radial ornament ramicostellate; concentric ornament of growth lirae and lamellae.

Dorsal interior has short, triangular, posteriorly sloping notothyrial platform; cardinal process bladlike, attached to inner face of chilidium; subsidiary ridges lacking. Brachio-phores widely divergent, small wedge-shaped protuberances on thickened ridges that nearly parallel posterior shell wall, enclosing laterally extended sockets. Median septum extends from beneath notothyrial platform to somewhat beyond mid-shell. Adductor muscle scars weakly impressed, radially disposed, subtriangular. Anterolateral margin of

shell floor defined by raised, medially re-entrant rim. Mantle canal system not known. Shell floor pustulose.

Ventral valve has wide teeth; spondylium elevated, long, rapidly widening. Median septum stout, extends well onto shell floor; lateral septa shorter and thinner, terminate at about edge of spondylium. Marginal rim as on dorsal valve; mantle canal system not known, shell floor pustulose.

*Discussion.* This genus is erected to contain the type species *J. hornei* n. sp., described below, and probably also includes the specimens I described as “*Polytoechia?* sp.” (Neuman, 1964, p. E22, E23, Pl. 1, figs. 14–17) known only from ventral valves.

In some respects *Jaanussonites* is like *Gonambonites*, and in others it resembles *Estlandia*. Unlike both these genera it has a ventral valve that is deeper than its dorsal valve and it lacks ridges subsidiary to the cardinal process on the notothyrium. The cardinalia are more posteriorly confined than they are in *Estlandia*, and in this respect *Jaanussonites* is nearer to *Gonambonites* and the thickening around the margin of the shell floor is like that of *Estlandia*.

*Jaanussonites hornei* new species

Plate 5, figs. 6–18

*Diagnosis.* Semicircular outline, ventribiconvex to concavoconvex in lateral profile; coarsely ramicostellate, the costellae hollow.

*Derivation of the name.* For G.S. Horne

*Material.* Holotype: dorsal valve, internal mould, GSC 35023. Paratypes figured and measured: 3 ventral valves, 2 internal moulds and counterpart external moulds, GSC 35028, GSC 35030 (internal mould not figured), internal mould, GSC 35027; 3 dorsal valves, 2 internal moulds, GSC 35024 and GSC 35026, internal mould and counterpart external mould, GSC 35025. Paratypes figured but not measured: ventral valve, internal mould and counterpart external mould, GSC 35029. Paratypes neither figured nor measured: 13 dorsal valves, 11 ventral valves.

*Description.* Medium to large shells, variable in profile from ventribiconvex to slightly concavoconvex. Outline semi-circular, widest at hinge, cardinal extremities near 90°, sides convergent towards broadly rounded front. Commissures straight; fold and sulcus lacking. Ventral interarea long, straight, sharply apsacline, meets base of shell floor at about 40°. Convex pseudodeltidium has large elliptical foramen near its apex. Beak erect, slope from beak to anterior margin has little curvature; slope from beak to lateral margin broadly rounded near middle, becoming concave near extremities. Dorsal valve has short hypercline to anacline interarea; notothyrium wide, covered by chilidium; profile variable, ranging from slightly convex to slightly concave. Radial ornament coarsely ramicostellate, the stronger costellae spaced at about 6 per 5 mm around the anterior margin

of shells about 15 mm long, enclosing 1 to 3 considerably weaker costellae; costellae rounded, hollow, somewhat narrower than interspaces (hollowness of costellae seen in external moulds as spiculelike threads of matrix along the impressions of costellae, oriented obliquely outward, some as long as 2 mm). Growth lirae closely spaced, somewhat stronger on interspaces than on costellae, developing into imbricate growth lamellae around anterolateral margins.

Dorsal interior has short triangular notothyrial platform elevated above shell floor and supported by base of median septum; notothyrial chambers shallow, wide. Cardinal process simple, bladelike, slightly thickened anteriorly. Ridges supporting brachiophores short, widely divergent, merge with shell floor slightly beyond midway between median septum and lateral anterior margins. Median septum a low ridge posteriorly becoming higher anteriorly to as much as 1 mm at about one-third shell length, then rapidly fading to extinction at edge of submarginal rim. Adductor muscle scars slightly thickened, subtriangular, their sides radiating from near apex of valve; posterior pair outward of and wider than anterior pair; anterior margins rounded. Inner two thirds or more of shell floor defined by raised rim of thickened shell subparallel to anterolateral margin of shell except medially where it is deflected inward toward terminus of median septum.

Ventral valve's elevated spondylium triplex is about as long as interarea; spondylium of some specimens has median groove, and some have pedicle calyst. Septa support the spondylium its full length. Median septum thicker than lateral septa, drops rapidly at anterior edge of spondylium to form low median ridge that extends as far as midlength of shell floor on some specimens. Lateral septa thinner, slightly convergent downward, and only slightly projected beyond edge of spondylium. Marginal rim like that of dorsal valve.

*Discussion.* The preservation of the specimens included in this species leaves much to be desired. All specimens are incomplete, and some are considerably deformed; the features described are therefore a composite. Grouped here are those gonambonitids in the Virgin Arm collection that have a submarginal rim, the dorsal valves having weakly impressed adductor muscle scars. The best preserved of such dorsal valves have relatively fine hollow costellae. Of the 11 ventral valves whose internal moulds have long septa beneath the spondylium, one has an external counterpart with ornament well enough preserved to show comparably spaced hollow costellae.

Of these 11, a uniformly concave spondylium is found in 9, whereas in 2 the spondylium has a median groove. Such a groove is considered to be a variable feature within the species. It was thought to link the specimens identified as "*Polytoechia?* sp." from the Shin Brook Formation of Maine with *Kullervo* (Neuman, 1964, p. E23). In neither those specimens nor these from Virgin Arm does the groove approach the depth or constriction of the hemisyrix of that genus.

Genus *Antigonambonites* Öpik, 1934

*Antigonambonites* sp.

Pl. 4, figs. 15–24

This distinctive brachiopod is represented by 19 specimens—14 dorsal valves and 5 ventral valves. Its ventribiconvex profile and the strongly developed adductor muscle scars in the dorsal valve place it with the *A. maekulaensis* group that was distinguished by Öpik (1934, p. 148).

*Measurements*

GSC no.	Length						Hinge width	Costellae
	total	interarea	disc and marginal rim					
			45° from midline	disc rim	midline	disc rim		
			(mm)					(/5 mm)
Dorsal valves								
holotype								
35023	18	1.5	15.0	5	13	5	25.0	(27) —
paratype								
35024	12 (13)	1.0	12.0	3	8	5	17.5	—
paratype								
35026	10 (13)	3.0	11.0	3	—	—	14.0	(15) 10.0
paratype								
35025	9	1.0	6.5	2	—	6.5	7.5	2.5
Ventral valves								
paratype								
35027	16 (19)	5.0	14.0	4	16 (3)	—	11.0	l.c. —
paratype								
35028	8	6.0			no rim		9.0	9.0
paratype								
35030	16	8.0			external mould		15.0	10.0

( ) Estimate. l.c. Laterally compressed.

*Description.* Large ventribiconvex shells, suboval in outline, wider than long, maximum width a little greater than hinge width, at about one-third shell length; cardinal angles a little more than 90°. Sides and anterior margin broadly rounded; lateral and anterior commissures straight. Dorsal valve has short anacline interarea, notothyrium wide, covered by arched chilidium. Beak low, curvature nearly uniform in lateral profile, thickest near middle; anterior profile has shallow sulcus occupied by about 6 costellae in posterior half; sulcus dies out toward front; flanks and front gently arched. Ventral interarea long, apsacline; delthyrium covered by pseudodeltidium having large subapical foramen. Beak high, shell slopes forward with little curvature; posterolateral flanks have shallow concavity; anterior part apparently variable, convex or slightly concave. Radial ornament coarsely ramicostellate, costellae rounded, steep-sided; costellar insertion in larger shells at three zones; 4 to 6 major costellae per 5 mm at the margins of shells 12 to 16 mm long. Concentric ornament of growth lirae in interspaces and of irregularly spaced growth lamellae 0.2 to 1 mm apart over both costellae and interspaces.

Dorsal interior has narrow, triangular, posteriorly sloping notothyrial platform supported by thickened shell tissue. Cardinal process simple, low, somewhat thickened anteriorly, merges with chilidium. Brachiophore supports are

poorly defined, supported by widely divergent round-topped ridges of thickened shell that enclose wide shallow sockets; angle between these ridges and posterior shell wall about 15°; ridges die out about midway between midline and shell edge. Median ridge low in front of notothyrial platform, grades forward into median septum; length of median septum variable, from coextensive with adductor muscle field to twice its length in gerontic specimens. Adductor muscle scars radially disposed, elevated above shell floor on thickened shell; outer posterior pair triangular, with nearly straight thickened anterior margins, which in gerontic specimens may be slightly lifted above shell floor; inner (anterior) adductors subelliptical, anteriorly expanding concavities. Mantle canal system not known; *vascula genitalia* deeply impressed in gerontic specimens. Radial ornament impressed around margins, reflects alternation of stronger and weaker costellae; marginal rim absent. Shell floor pustulose.

Ventral interior has medially grooved spondylium triplex raised above shell floor only at anterior margin; median septum short, thick; lateral septa somewhat thinner, longer, divergent. Mantle canal system unknown; *vascula genitalia* deeply impressed on gerontic shells. Marginal rim absent and shell floor pustulose as on dorsal valve.

#### Measurements

GSC no.	Length		Width		Thickness	Costellae (/5 mm)
	total	interarea	hinge	max.		
			(mm)			
Dorsal valves						
35031	12	1	17	18	2.0	4
35032	13	—	16	19	—	—
35033	8	1	10 (12)	11 (12)	1.5	—
35035	11	1	17	18 (19)	2.0	—
Ventral valves						
35034	17	8	19	24	4.0	—
35036	16	5	17 (24)	26	3.0	6

( ) Estimate.

*Discussion.* Specimens assigned to this species show considerable variation, not all of which is attributable to tectonic deformation. One dorsal valve and two ventral valves appear from their deeply impressed mantle canals to be gerontic specimens; the ventral valves have very long interareas, suggesting that this is a gerontic feature.

In establishing *Antigonambonites*, Öpik (1934, p. 148) identified three species groups: the *planus* group having strophomenoid curvature and barely evident dorsal musculature; the *maekulaensis* group having strongly impressed muscle scars; and the *aequistriatus* group having a strongly developed ventral margin, strong intervascular ridges and relatively coarse concentric ornament.

The elevated and well defined dorsal muscle scars of the specimens described here link them with the *maekulaensis* group, although they cannot be assigned to any of the three species of that group. All specimens assigned to the genus and illustrated by Öpik (1934) have a marginal rim, and in this are different from the specimens in this suite. Convexity varies among the specimens in this suite: it may be an

intraspecific variable. Compared with the species of the *maekulaensis* group, these specimens are not as alate as *A. sulcatus*, and the alternation of coarse and fine costellae is more evident in them than it is in either *A. maekulaensis* or *A. sulcatus*.

Subfamily ANOMALORTHINAE Ulrich and Cooper, 1936

Genus *Progonambonites* Öpik, 1934

*Progonambonites* sp.

Pl. 4, figs. 1–14

The 30 specimens assigned to this genus include the largest individuals in the Virgin Arm assemblage.

*Description.* Large, subquadrate, ventribiconvex shells, wider than long, cardinal angles near 90°, maximum width somewhat greater than hinge width, anterior margin broadly rounded. Ventral interarea moderately long, concave, apsacline, about twice as long as anacline dorsal interarea. Delthyrium and notothyrium wide, open, without modifying plates or coverings. Lateral profile broadly arched, ventral valve nearly twice as deep as dorsal valve. Dorsal valve has broad low sulcus, somewhat inflated flanks and slightly concave posterolateral slopes. Ventral valve has corresponding low fold and similarly concave posterolateral slopes. Anterior commissure gently sulcate. Radial ornament parvicostellate, costellae rounded, 1 to 4 weaker ones between stronger ones; costellae inserted at intervals of about 5 mm, the newly inserted costellae of subordinate strength to the older ones; about 7 costellae per 5 mm at the anterior margin of shells 15 to 20 mm long. Concentric ornament of strong crowded growth lirae throughout shell length over costellae and interspaces alike; a few stronger growth lamellae, irregularly spaced at 1- to 2-mm intervals toward the front.

Dorsal interior has short elevated notothyrial platform bearing thin bladlike cardinal process its entire length. Brachioophores low, rounded, widely divergent ridges extended laterally as thickenings of shell floor, curving posteriorly. Median septum short, confined to posterior third of valve. Pair of platforms elevated above shell floor presumably sites of adductor muscle attachment. Platform subtriangular, supported by three radially disposed plates of unequal length; inner plate diverges from median septum at about 20°, intermediate plate about 10° beyond, and outer plate about 20° beyond that. Inner plate longest, about one-third longer than platform and about as long as median septum; intermediate plate about as long as platform; outer plate slightly longer than platform. Platform rises anteriorly away from shell floor. Floor of platform differentiated, inner third slightly higher than outer two thirds, low ridge between parts coincident with intermediate supporting plate. (Posterior adductor muscle scar may be outer part of platform, anterior adductor the interior part; see Öpik, 1934, p. 215, Fig. 49, and Rubel, 1963, p. 103, Fig. 8.) A pair of short ridges lies between outer parts of median

septum and inner platform support plates. Shell floor densely and finely pustulose; shell presumably pseudopunctate. Mantle canal system not seen. Subperipheral margin in some specimens. Ornament weakly impressed around antero-lateral margin.

Ventral interior has laterally extended teeth and broad shallow spondylium triplex. Spondylium short (about one-fifth shell length), medially depressed, entirely elevated above shell floor on median septum; anterior termination ankylosed to median septum. Median septum strong, increasingly high and attached to advancing spondylium to termination of spondylium, where septum lowers abruptly, extending anteriorly as low ridge to gradual extinction at about mid-shell. Lateral septa incompletely developed, consisting of short radial ridges on underside of spondylium about half-way between median septum and posterior shell wall, and confined to middle two thirds of its length (seen only when spondylium is viewed from anterior, or, in internal moulds, when seen from posterior (Pl. 4, fig. 14); otherwise hidden by spondylium, or by filling of shell floor on internal moulds). Mantle canal system not seen. Internal surface pustulose; subperipheral margin and internal impression of ornament as on dorsal valve.

#### Measurements

GSC no.	Length		Width		Thickness	Costellae (/5 mm)
	total	interarea	hinge (mm)	max.		
Dorsal valves						
35012	26	1.5	30	34	3.0	—
35013	20	1.5	25	26	2.5	—
35014	21	2.0	20 (22)	20 (22)	2.5	9
35015	22	1.5	33	32 (35)	3.0	—
Ventral valves						
35016	15	2.5	22	24	3.0	7
35018	19	3.0	22	25	6.0	7

( ) Estimate.

*Discussion.* In size, proportions and ornament pattern, this species resembles *P. estonus* Öpik and *P. inflexus* (Pander) of late Arenig (B III) age from the Russian Platform as these species were redescribed by Rubel (1963, p. 95–98); *P. estonus* has costellae spaced at 7 per 5 mm, comparable to this species. The pre-Baltic species do not have elevated platforms in their dorsal valves, although Rubel (1963, Pl. 5, fig. 4) illustrates a specimen of *Gonambonites parallelus* (Pander) of the same age having similar platforms.

#### Order STROPHOMENIDA Öpik, 1934

##### Suborder STROPHOMENIDINA Öpik, 1934

##### Superfamily PLECTAMBONITACEA Jones, 1928

##### Family PLECTAMBONITIDAE Jones, 1928

##### Subfamily PLECTAMBONITINAE Jones, 1928

##### Genus *Ingria* Öpik, 1930

##### *Ingria* sp.

Pl. 6, figs. 19–29

Among the 29 incomplete specimens in the Virgin Arm assemblage (22 dorsal valves, seven ventral valves) assigned

to this genus, are a few external moulds in which the ornament is well preserved, showing that the growth fila are very fine and subdued; Öpik (1932, p. 17) stated that such concentric ornament was diagnostic of the group of *I. pakriana* Öpik.

*Description.* Convexiconcave to resupinate, thin-bodied strophomenoid shell, subtriangular in outline, wider than long. Cardinal angles slightly less than 90°, sides anteriorly convergent, broadly rounded, front broadly to narrowly rounded. Interareas short, horizontally striated; apsacline ventral interarea about one-third longer than anacline dorsal interarea. Delthyrium narrow, covered by pseudodeltidium; no foramen seen. Notothyrium correspondingly narrow, with chilidium. Profile of ventral valve variable, flat to gently convex shells less than 10 mm long, and to about 10 mm in larger shells with shallow concavity beyond. Dorsal valve mostly of low convexity with shallow concavity in posterolateral corners, and steepened slopes near anterior margin. Lateral commissure straight to gently sinuous, the latter dorsally directed behind and ventrally directed in front. Neither fold nor sinus present; anterior commissure straight. Radial ornament of widely spaced, low narrow linelike costellae, most extending from near beak to shell margin, only a few inserted anteriorly; costellae spaced at 1.5 to 3 mm in shells 10 mm or more long; costellae absent from posterolateral corners. Concentric ornament of closely spaced fila that pinch and swell on a very fine scale to give a very fine reticulate pattern. Shell pseudopunctate.

Dorsal interior has short indistinctly defined notothyrial platform, essentially a thickening of medial segment of posterior shell wall with convex curvature, back part facing posteriorly, medial part facing ventrally, front part facing anteriorly and curving under to form roof of shallow notothyrial chambers; medially supported by low median ridge. Cardinal process simple, high in middle, low posteriorly where it meets chilidium and anteriorly where it fades to floor of notothyrial platform. Brachiophore supports (socket ridges) project laterally from margins of notothyrium as thickened shell tissue rising from shell floor, curving posteriorly toward posterior shell wall, outlining raised wide sockets, and terminating somewhat beyond midpoint between centreline and shell margin, termination corresponding to posterior edge of subperipheral ridge. Medial segment of hingeline crenulated or denticulate in 2 of 20 specimens that have this part of shell preserved. Median ridge low, broad, short, bifurcates at 2 to 3 mm from posterior shell wall, branches dying out a short distance beyond that. Adductor muscle scars are shallow excavations, posteriorly confined, radially disposed, resembling pair of mittens; outer (posterior) pair (the thumb) narrow, short, set off by re-entrant from wider longer inner (anterior) pair. Pair of broad low crescentic ridges emanate from anterior edge of inner diductor scar, convex face of crescent directed posterolaterally; mantle canals not otherwise expressed. Low subperipheral ridge encloses oval area somewhat different in outline from that of shell, rounded at posterolateral extremities, widest at midlength, and broadly rounded at front. Shell floor pustulose. Margin bears about twice as many grooves as costellae, half of which correspond

to costellae, suggesting that intercostellar grooves represent incipient costellae.

Ventral valve has short teeth; hingeline denticulate all along one specimen, the inner half of another, and not denticulate in 3 others. Dental plates very short, widely divergent. Muscle area short, cordate; slightly thickened anterior margins of diductor scars meet in re-entrant at midline; adjustor scars large, shorter than diductors and flanking them; adductor scar small, weakly impressed, enclosed by diductors. Subperipheral ridge low, outlines oval area as in dorsal valve; floor of area enclosed, marked by fine closely spaced striae in some specimens. Internal surface of shell pustulose; no mantle canals seen. Margins of some specimens have impressions of costellae as on dorsal valve.

#### Measurements

GSC no.	Length				Hinge width	Costellae
	total	inter-area	muscle	to sub-peripheral ridge		
	(mm)					
Dorsal valves						
35037	11	1.0	—	7.0	15 (16)	ca. 10
35038	19	1.0	4.0	10.0	27	17
35039	13	1.5	3.0	9.0	20	—
35040	11 (?)	0.75	2.5	6.5	13 (?)	—
Ventral valves						
35041	13	1.5	3.3	9.0	18	—
35042	8	1.0	2.0	5.5	11	—

( ) Estimate.

*Discussion.* The hinge denticulation of *Ingria* is different in kind and frequency of occurrence from later stocks of strophomenids. In the younger stocks there is a clear distinction between toothed and socketed hinges: the former are a row of protuberances, whereas the latter are recesses. No such distinction can be made in the denticulation of the opposite valves of *Ingria*. Unlike the persistent occurrence of denticulation in specimens of the younger stocks, among the specimens in suites of *I. claudi* Ulrich and Cooper from Nevada, the few from Estonia in the U.S. National Museum collections and these from Newfoundland, there are some denticulate the full length of the hinge, some to varying degrees, and some not denticulate.

The Newfoundland species has the length-width proportions of the Baltic species rather than the elongate form of *I. claudi*. Two indistinctly separated species groups were identified among the Baltic species by Öpik (1932, p. 17): the group of *I. nefedyevi* with well-defined concentric sculpture (“*Querskulptur*”) and the group of *I. pakriana* in which the concentric sculpture is more or less indistinct.

Compared with the specimens illustrated by Öpik (1932), the wide spacing of radial costellae of the Newfoundland specimens is most like the specimen of *I. nefedyevi* of his Pl. 10, figs. 43 and 44, but their concentric ornament is not as pronounced as that of another specimen of the same species illustrated to show this characteristic (Öpik, 1932, Pl. 7). The Newfoundland specimens seem therefore to belong to an unnamed species of the group of *I. pakriana*.

#### Subfamily AHTIELLINAE Öpik, 1933

#### Genus *Ahtiella* Öpik, 1932

#### *Ahtiella paucirugosa* new species

Pl. 3, figs. 24–37; Pl. 8, fig. 1

*Diagnosis.* Sulcate *Ahtiella* having few or no rugae.

*Derivation of the name.* Latin *paucus* (few) + *ruga* (wrinkle)

*Material.* Holotype: ventral valve, internal mould and counterpart external mould, GSC 35050. Figured paratypes: 2 articulated internal moulds (their external counterparts not illustrated), GSC 35051, 35052; 2 ventral valves, internal moulds and counterparts, external moulds, GSC 35055, 35056; 2 dorsal valves, internal moulds, the counterpart external mould of one present but not illustrated, GSC 35053, 35054; thin section of part of dorsal valve, GSC 35057. Paratypes not figured or measured: 12 articulated valves, 6 dorsal valves, 7 ventral valves.

*Description.* Medium to large, convex-concave, geniculate, subtriangular to semielliptical shells, wider than long, widest at hinge, cardinal extremities alate to sharply acute. Sides anteriorly convergent, broadly rounded, front broadly to narrowly rounded. Ventral interarea catacline to steeply apsacline, about one-third longer than anacline dorsal interarea; delthyrium and notothyrium covered by arched pseudodeltidium and chilidium, respectively. Lateral profile geniculate, disc resupinate; dorsal valve posterior 1 to 2 mm, flat to slightly concave, becoming convex beyond; thickest at about midlength; zone of geniculation not sharp, corresponds with internal rim; trail length about half that of disc. Ventral disc of low convexity in posterior 1 to 2 mm, with low beak, becoming concave anteriorly to zone of geniculation. Disc of dorsal valve bears narrow, well defined sulcus, that of ventral valve has corresponding fold; fold and sulcus less well defined on trails. Ornament of disc dominantly radial, of fine parvicostellae, that of trail dominantly concentric, of fine growth fila. At geniculation zone, about 10 mm shell length, stronger costellae spaced about 1 per mm (range from 0.75 to 1.5 mm), with 3 to 4 finer costellae between them. Oblique rugae absent from most specimens; where present, as many as 8 directed from the flanks toward the posterolateral margins. Concentric ornament obscure in disc area. Shell structure coarsely pseudopunctate (Pl. 8, fig. 1).

Dorsal interior has low sessile triangular notothyrial platform; cardinal process simple, narrow and low posteriorly, wider and higher anteriorly. Brachiophore bases short, erect, expanded anteriorly, diverge from each other at about 90°; lateral edges of sockets outlined by thickened shell in some specimens. Median ridge broad and low in front of notothyrial platform, becomes high and septumlike at midlength, dies out at peripheral rim. Adductor muscle scars variably impressed; in one specimen posterior and anterior pair separated by low transverse ridge, posterior pair pentagonal in outline, slightly smaller than anterior pair; in other specimens, adductor scars are undifferentiated,

anteriorly expanded, drop-shaped, extending to about midlength of disc. Mantle canal system saccate, the *vascula myaria* describing arc from anterolateral edge of adductor scars towards posterolateral corners, enclosing radially grooved *vascula genitalia* that occupy as much as half disc area. *Vascula myaria* directed anteriorly from anteriormost tip of adductor scars to rim, beyond which they are not visible. Disc set off from trail by low rounded ridge at zone of shell geniculation. Disc deepest in front third, the thickest part of body cavity. Floor of shell in both disc and trail has coarse pustules in rows on crests of fine striations.

Ventral valve has short wide teeth; dental plates low, widely divergent, extended as low ridges at sides of muscle field. Muscle field wide and long; diductor scars about twice length of adductors, extend to about midlength of disc; each diductor scar about as wide as adductor track; anterior ends of both slightly thickened. Mantle canal system saccate, *vascula media* branched at origins at anterior ends of diductor scars, a lateral branch curving toward posterolateral corners enclosing radially grooved *vascula genitalia*, anterior branches directed obliquely with little branching within disc. Edge of disc sharply upturned rim. Internal surface of disc and trail pustulose as in dorsal valve.

#### Measurements

GSC no.	Length				Hinge width
	disc	trail	interarea	to edge of muscle scar	
			(mm)		
Dorsal valves					
paratype 35053	10	5	1.3	6	16 (18)
paratype 35054	14	5	1.2	7	22
Ventral valves					
holotype 35050	9	9	1.8	—	26
paratype 35055	11	—	1.0	3	24
paratype 35056	12	7	2.0	4	26

( ) Estimate.

**Discussion.** The deeply sculptured interiors of the specimens included in this species, their pronounced dorsal sulcus and ventral fold and their variable and weak rugosity distinguish them from other species of the genus described to date (Öpik, 1932, p. 37–43; Hessland, 1949). The only Baltic species lacking rugae is *A. arenaria* Öpik (1933, p. 19, 20, Pl. 4, figs. 7–9) from the Rõgo Sandstone (B III) of Estonia; it lacks a fold and a sulcus. *A. concava* Bates (1968, p. 167–169, Pl. 7, figs. 14–22) from the Bod Deiniol Formation, Anglesey, is not rugose but details of its ornament are not preserved; the musculature of this species is different from that of *A. paucirugosa* and it lacks a rim separating the disc from the trail. *A. quadrata* Bates (1968, p. 166, 167, Pl. 9, figs. 1–9) from the Torllwyn Formation, Anglesey, is not rugose but it is more quadrate and more coarsely costellate than any other species of the genus.

### Genus *Guttasella* new genus

**Diagnosis.** Wide, nonrugose, parvicostellate, gently resupinate, doubly geniculate shells, the trail deflected first ventrally, then dorsally along a deep marginal trough or gutter facing dorsally.

**Derivation of the name.** Latin *gutta* (drop)

Type species and only species assigned. *Guttasella gutta* new species

**Description.** Large, thin-bodied shell, wider than long, having concavoconvex disc about four fifths of shell length, and doubly geniculated trail whose inner half is gradually bent ventrally and outer half sharply turned dorsally, the reversal of flexure forming sharply defined trough or gutter around anteromedial margin of dorsal valve and corresponding peripheral ridge around margin of ventral valve. Shell outline subquadrate to shield-shaped, widest at hinge, somewhat longer than shell in plan view. Chilidium probably present, delthyrium probably open. Radial ornament parvicostellate; concentric or oblique rugae lacking. Shell structure pseudopunctate.

Dorsal interior poorly known: notothyrial platform low, long, triangular, its anterior margin a rounded thickening of shell. Cardinal process a long blade, slightly thickened anteriorly. Brachiophores very short, divergent, wedge-shaped. Adductor muscle scars quadripartite, posterior pair smaller than bilobed anterior pair. Boundary between disc and trail poorly defined; trail marked by closely spaced branches of mantle canals. Shell floor finely pustulose.

Ventral interior also poorly known: dental plates very short, erect, advancing, curved, merging forward with low ridges to form sides of muscle field; outline of muscle field probably cordate. Edge of disc is low rounded rim. Pustules on internal surface and distal mantle canals as on dorsal valve.

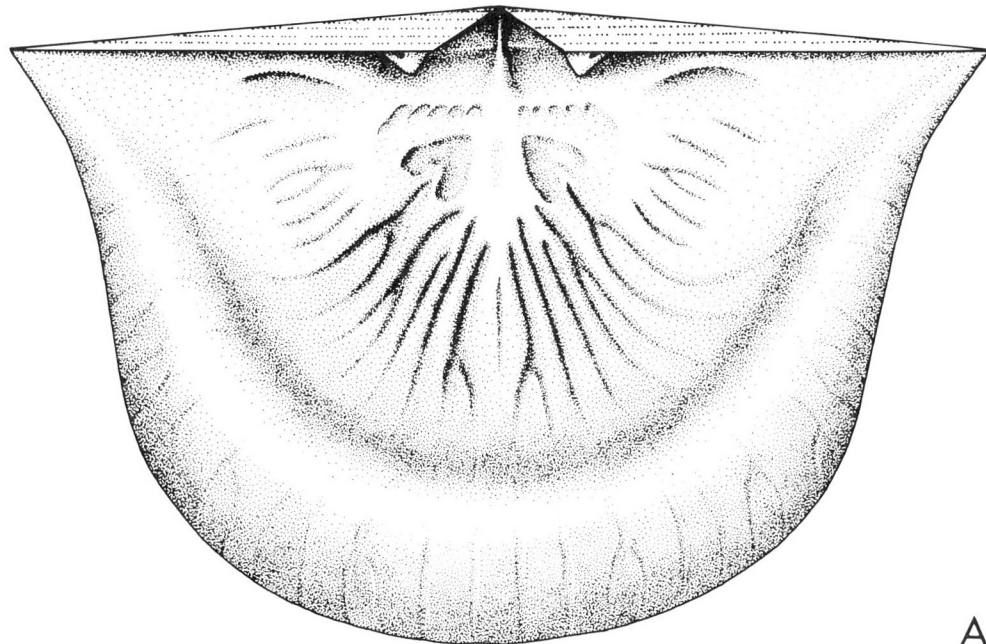
**Discussion.** This monotypic genus is erected to contain the type species *G. gutta* n. sp., described below. Although this species is based on manifestly unsatisfactory material, the combination of features preserved cannot be accommodated in any genus of ahtielinids described to date. The profile of its disc and the geniculation of its trail are like those of *Reinversella* Bates (1968, p. 169) and their cardinalia and musculature are comparable as far as poor preservation of both genera permits them to be observed. *Reinversella*, however, has concentric rugae over the entire disc, whereas *Guttasella* has no rugae on its disc.

#### *Guttasella gutta* new species

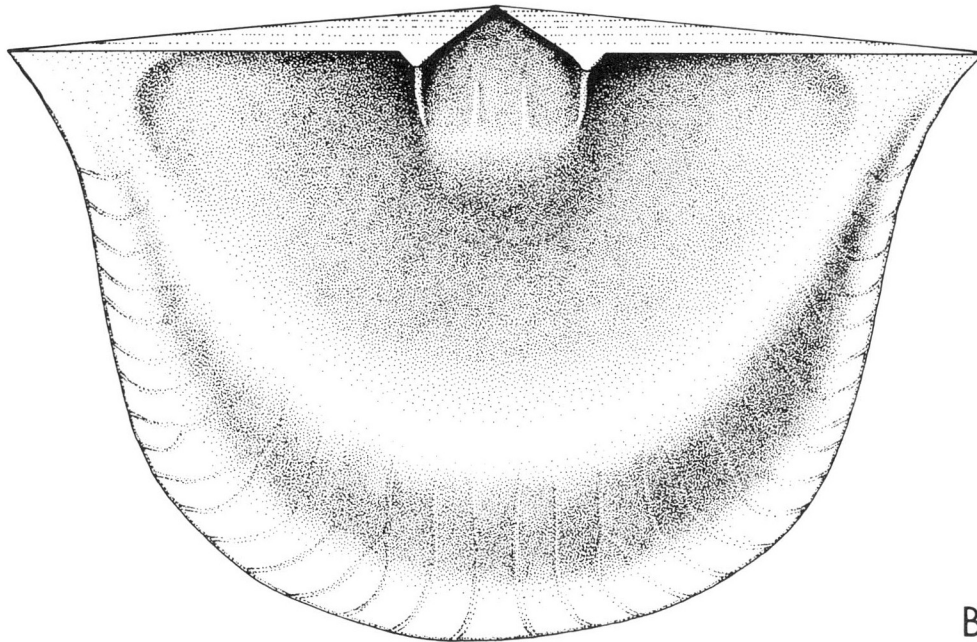
Pl. 5, figs. 1–5; Fig. 3

**Diagnosis.** Large *Guttasella* having ornament of fine parvicostellae and closely spaced growth fila.

**Material.** Holotype: dorsal valve, incomplete internal and external mould, GSC 35058. Paratypes figured and measured:



A



B

Figure 3. *Guttasella gutta* n. gen., n. sp., reconstructions  $\times 3.5$ . A, dorsal valve, B, ventral valve, based on holotype (GSC 35058) and paratype (GSC 35059), respectively. Chlidium omitted from dorsal valve so as not to obscure structures beneath it; details of central part of floor of ventral valve not shown for lack of information. (Drawings by Elsie Herbold Froeschner.)

2 ventral valves, internal and external moulds, GSC 35059, 35060. Paratype measured but not figured: ventral internal mould, GSC 35061.

*Description.* Large, subquadrate to shield-shaped geniculate shells, widest at hinge, cardinal extremities acute or somewhat alate; sides somewhat sigmoidal, concave outward in posterior fourth, then broadly convex, merging with broadly rounded anterior margin. Interareas subequal; ventral interarea steeply apsacline, only slightly longer than anacline dorsal interarea. Delthyrium apparently open (no evidence of pseudodeltidium); notothyrium probably covered by chilidium. Disc of dorsal valve gently concave in posterior half, becoming convex anteriorly and merging with ventrally sloping segment of trail; boundary between disc and trail gradational. Boundary between ventrally and dorsally facing segments of trail a U-shaped trough or gutter, best developed around anterior margin where it is ventral to commissural plane of disc; trail with trough diminishes along shell sides to extinction in posterolateral corners. Dorsally facing segment of trail nearly normal to commissural plane of disc, its length about that required to bring anterolateral commissure of shell to level of commissural plane of disc. Disc of ventral valve moderately convex in posterior half, flattening anteriorly and merging with inner, ventrally directed segment of trail; then flexing abruptly along sharply rounded peripheral ridge, the vertical, dorsally directed outer segment of trail. Radial ornament finely parvicostellate, coarser costellae about 1 mm apart at outer edge of disc, most with 5 finer costellae between them. Finer costellae increase by insertion; some increase to size of coarser ones; spacing of costellae greater on outer segment of trail, about 5 per 10 mm, where they include about 10 fine ones. Concentric ornament of closely spaced growth fila about equal in spacing and amplitude to finer costellae, giving cancellate pattern.

Dorsal interior known from a single specimen; notothyrial platform large, low, triangular, with low transverse ridge at midlength and with fluted anterior thickening. Cardinal process thin, bladlike posteriorly, highest at midlength at intersection with transverse ridge, lower and wider anteriorly. Brachiophore bases (one seen) very short, wedge-shaped, set behind anterior margin of notothyrial platform. Sockets shallow grooves on posterolateral faces of brachiophores. Obliquely directed ridge forms strut between posterior margin of shell floor and underside of posterior shell wall. Adductor scars large, mitten-shaped, thickened at anterolateral margins, posterior pair smaller and outside anterior pair. Mantle canal system saccate; *vascula myaria* originate in depressions between lobes of adductor scars, lateral branches curving posterolaterally to enclose radially striated *vascula genitalia*; *vascula media* originate as branching furrows in midpart of disc. Distal branches well impressed on inner and outer segments of trail, spacing about that of coarser costellae. Boundary between disc and trail indistinct, at zone of geniculation from concave floor to convex rim, without ridge or furrow. Shell floor finely pustulose.

Interior of ventral valve poorly known; delthyrial cavity shallow, dental plates short, advancing, joined at their

bases with curved lateral margins of muscle field. Muscle field short, wide; diductor scars narrow anteriorly, adductor track widens, both about same length, anterior margins thickened. Floor of central part of disc shallow, concave, becoming convex anterolaterally. Boundary between disc and trail without sharp demarcation, at zone of flexing from convex to concave. Proximal trunks of mantle canal system not seen; distal branches extend across trail from outer edge of disc, some with as many as 3 dichotomies. Shell floor finely pustulose as on dorsal valve.

#### Measurements

GSC no.	Length						Hinge width
	disc	inner trail	outer trail	total	inter-area	to edge of muscle field	
							(mm)
Dorsal valve holotype 35058	17	7	5	29	2.0	10	12 (?)
Ventral valves paratype 35059	15	8	5	28	2.5	5	14 (40)
paratype 35061	14	5	7	26	—	—	42 (?)
paratype 35060	11	7	6	24	—	—	24 (?)

( ) Estimate.

*Discussion.* The doubly geniculate trail preserved on the 4 fragmentary specimens of the type suite is the most conspicuous feature of the species and the genus erected to contain it. The wide-hinged outline of the shell, which is partly preserved on the 3 ventral valves, was used in the reconstruction of both valves (Fig. 3).

Inside the single specimen of a dorsal valve, the notothyrial platform, the cardinal process and the adductor musculature are well preserved but only one brachiophore and its included socket survive and this structure may be incomplete or deformed. A chilidium, omitted from the reconstruction so as not to obscure other features, is inferred from the former presence of shell beneath the edges of the notothyrial platform but the continuity of this shell beneath the platform was not observed; if it is discontinuous the structure would be a pair of chilidial plates.

Details inside the ventral valve are known even less. No specimens preserve teeth, although the narrow socket of the dorsal valve suggests that teeth are correspondingly delicate. The short dental plates and the wide muscle field are visible in two specimens but details within the muscle field are obscure in both of them. Although the distal branches of the mantle canal system are well preserved on the trails of all specimens and the main trunks are decipherable in the dorsal valve, they are obliterated in the disc of the ventral valve.

*G. gutta* most resembles *Reinversella monensis* Bates (1968, p. 169, 170) both in internal morphology and in geniculation, although *R. monensis* has a rugose disc.



Genus *Inversella* Öpik, 1933*Inversella* sp.

Pl. 6, figs. 1–4

An unidentified species of this genus is represented at Virgin Arm by five dorsal valves and one ventral valve, none well preserved.

*Description.* Shells of average size for genus, wider than long, widest at hinge; disc gently resupinate, rugose, subelliptical; trail sharply flexed dorsally. Interareas short, ventral apsacline, dorsal anacline; notothyrial or delthyrial coverings not determinable. Posterior half of disc of dorsal valve gently concave, becoming gently convex beyond; outer edge of disc a gutter, inner margin of trail flexed steeply (90° or more), flaring outward in larger specimens. Posterior half of disc of ventral valve of low convexity, flattening and becoming gently concave beyond to marginal ruga and trail. Rugosity of both valves better developed in anterolateral parts of disc than in inner part, commonly 4 wrinkles on each valve; trail not rugose; rugae wavelength on outer disc about 1.5 mm. Radial ornament of fine costellae, about 7 per mm, undifferentiated except for single strong median costella on dorsal valve.

Dorsal valve has orthoid cardinalia; notothyrial cavity shallow, notothyrial platform without shell thickening; cardinal process simple, bladelike. Brachiophores short, delicate, erect, with sharply pointed terminations. Adductor muscle scars not seen. Internal surface finely and densely pustulose; rugosity and radial ornament impressed on valve floor.

Ventral interior poorly known; dental plates short, receding, musculature not known.

*Measurements*

GSC no.	Length			Width	Rugae	Costellae per mm
	disc	trail	interarea			
			(mm)			
Dorsal valves						
35062	12	2	0.5	18 (22)	4	7
35064	15	9	—	44	—	7
35065	9	2	1.0	21	3	7
Ventral valve						
35063	11	2	1.5	9 (18)	4	7

( ) Estimate.

*Discussion.* Although this species is incompletely known from few and fragmentary specimens, enough is preserved for confident assignment to this genus. The smaller specimens have relatively short trails, but the trails of the larger ones are similar in length to those previously illustrated (see especially: *I. angulata* Öpik, 1933, Pl. 3, fig. 3 and *I. perundosa* Öpik, 1939, Pl. 5, fig. 6). Details of the ornament of these specimens are imperfectly preserved but the major median costella and otherwise undifferentiated fine costellation are comparable to those of *I. perundosa*.

Öpik (1939, p. 128) characterized the three known species of *Inversella* by the rounded geniculation (*Knie*) of *I. borealis* compared with the sharper geniculation of *I. angulata* and *I. perundosa*; the disc of *I. angulata* is longer and less wrinkled than that of *I. perundosa*. These New-

foundland specimens are sharply geniculate, have a relatively short disc with few wrinkles, and thus do not clearly belong to any of these species.

## Family TAFFIIDAE Ulrich and Cooper, 1936

Genus *Taffia* Ulrich in Butts, 1926

The name *Taffia* was first used in Charles Butts's comprehensive report on the Paleozoic rocks of Alabama (Butts, 1926, p. 99), one of "two undescribed genera of brachiopods, for which (E.O.) Ulrich proposes the name *Taffia*." The name "*Taffia plano convexa*" was first used in the explanation of Butts's Plate 18 (Butts, 1926, p. 100), referring to three specimens without designation of a type nor showing internal structures. Ulrich and Cooper (1938) formally described both the genus (p. 180), attributing it to Ulrich, and the type species *T. planoconvexa* (p. 181), attributing it to Butts; two of the specimens from the 1926 plate were reillustrated and designated syntypes, and two dorsal valves and a ventral valve showing internal features were illustrated anew. Cooper in 1956 (p. 1175) designated one of the two previously designated syntypes as lectotype for the species, reillustrated the specimens shown in the 1938 paper and added one new illustration of a specimen showing the interior of a ventral valve.

Among the features cited as diagnostic of *Taffia* is the absence of a cardinal process (Ulrich and Cooper, 1938, p. 180): two specimens devoid of a cardinal process were illustrated both in 1938 (Ulrich and Cooper, 1938, Pl. 37, figs. 14, 18) and in 1956 (Cooper, 1956, Pl. 172, figs. 28, 29). In explaining his illustrations, however, Cooper (1956, p. 1175) erroneously called attention to the cardinal process of one of them. This error seems prophetic after examination of another suite of specimens (USNM 166715) from the Odenville Limestone collected in 1938 (USGS loc. 488-CO: NW1/4, NW1/4, sect. 11, T. 18 S., R. 1 W., Vandiver quadrangle, Alabama, collected by G. A. Cooper, Josiah Bridge and others). Of the 39 specimens in this suite, 12 have exposed cardinalia; of these, 3 have a low but definite simple cardinal process and in 9 the floor of the notothyrial platform is smooth. The diagnosis of the genus should therefore be emended to indicate that a cardinal process may be present.

The distinction between *Taffia* and *Aporthophyla* cannot be based on the absence of a cardinal process in the former and its presence in the latter (Ulrich and Cooper, 1938, p. 182). The difference between them lies more in the larger size of *Aporthophyla*, its greater length-width ratio, and in its incompletely developed pseudodeltidium (Neuman, in Neuman and Bruton, 1974, p. 86).

*Taffia?* sp.

Pl. 7, figs. 16–21; Pl. 8, fig. 2

Although 21 ventral valves from Virgin Arm are assigned to this species, only one dorsal valve in the collection has features that indicate its probable association with them.

*Description.* Medium-size ventral valve, moderately convex, semielliptical in outline, slightly wider than long. Widest at hinge, cardinal angles about 80°, sides rounded, convergent anteriorly, front broadly rounded. Interarea apsacline, short, slightly concave, horizontally striated; delthyrium covered by pseudodeltidium lacking foramen. Beak low, lateral slopes of low uniform curvature; anterior slope of low convexity in posterior half, steepening anteriorly. Lateral and anterior commissures straight. Radial ornament rami-costellate; costellae are low, rounded over most of shell, 2 to 5 weaker costellae between stronger ones, stronger costellae spaced at about 1 per mm at 8- to 10-mm shell length. Shell thickens around anterolateral margins, radial ornament becoming subordinate to closely spaced growth lamellae.

Ventral interior has short subtriangular teeth; dental plates stout, short, nearly vertical. Delthyrial cavity moderately deep; muscle area short, about one-quarter shell length, on slightly thickened shell, subtriangular, with a broadly rounded, slightly thickened anterior margin, the adductor track extending slightly beyond the diductors. Width of adductor track about half total muscle area width; adductors set slightly below diductors and separated from them by pair of low ridges. Mantle canal system saccate, *vascula media* branching at about midlength, a posterolateral branch enclosing weakly impressed *vascula genitalia*; an antero-medial branch curves toward a medial groove that is impressed through front half of shell, branches and groove together forming tridentlike pattern. Marginal rim narrow, flaring outward on most specimens, bears impression of radial ornament. Surface of shell floor smooth, without pustules. Thin section of shell fragment near shell middle (Pl. 8, fig. 2) shows lamellar structure without pseudopunctae (compare with Pl. 8, fig. 1).

Dorsal valve similar in outline to ventral valve, transversely semielliptical, of very low convexity. Interarea anacline, very short; notothyrium covered by chilidium. Notothyrial platform very short, posteriorly directed, on thickened shell; cardinal process simple, bladelike, merges with chilidium posteriorly. Brachiophores orthoid, short, wedge-shaped, widely divergent; sockets shallow, elevated above shell floor. Adductor muscle scars are poorly preserved shallow excavations, separated by low median ridge in posterior third of valve. Marginal rim narrow, curved outward, with grooves that reflect radial ornament.

#### Measurements

GSC no.	Length			Hinge width	Thickness
	total	interarea	muscle field		
	(mm)				
Ventral valves					
35044	11.5	2.5	3.0	13.0	2.5
35045	11.0	2.0	3.5	11.0 (14)	2.0
35047	10.0	2.5	2.5	15.0	2.2
35048	11.5	3.0	3.0	18.0	2.0
Dorsal valve					
35046	7.0	0.5	—	11.5	—

( ) Estimate.

*Discussion.* This is an anomalous group of specimens of uncertain identification for several reasons, principally the uncertainty that the single dorsal internal mould described here is relevant to the 20 specimens of ventral valves. In other species in this and similar collections of dissociated valves, the linkage of dorsal with ventral valves of appropriate morphology was confirmed by identity of ornament, and valves so linked were of similar abundance.

The ventral valves in this suite have a combination of characteristics that indicates caution; their internal and external features suggest they be assigned to *Taffia*, a genus with pseudopunctate shells, whereas their shell structure is apparently impunctate. One might assume that such ventral valves have similarly taffiid dorsal valves, but alternative assumptions might indicate more orthoid or clitambonitid structures. A true and confirmed total shell morphology may be important for interpreting the origins of the strophomenoids.

#### Family LEPTELLINIDAE Ulrich and Cooper, 1936

#### Subfamily LEPTELLININAE Ulrich and Cooper, 1936

#### Genus *Calyptolepta* new genus

*Diagnosis.* Wide, concavoconvex, parvicostellate shells, the dorsal valve having a chilidium and a bladelike cardinal process, the ventral valve having an apically perforate pseudodeltidium; platform present on both valves, that of the dorsal valve having a high median crest, that of the ventral valve having a low ridge between its deeply impressed inner margins.

*Derivation of the name.* Greek *calypto* (cover) + *lepta*

Type species and only species assigned. *Calyptolepta diaphragma* new species

*Description.* Wide-hinged, concavoconvex leptellid shells, semielliptical to subtriangular in outline. Ventral interarea apsacline, with apically perforate pseudodeltidium; dorsal interarea catacline to hypercline with notothyrium covered by chilidium. Dorsal valve has depressed beak, maximum concavity beyond midlength; ventral beak low, shell swollen near middle. Radial ornament parvicostellate.

Dorsal interior has short posteriorly facing notothyrial platform bearing simple bladelike cardinal process. Sockets above shell floor on thickened shell, their lateral margins lifted, linking posterior shell wall and brachiophore bases (*cf.* fulcral plates). Brachiophores lathlike, with sharply pointed anterior terminations well above shell floor. Median ridge low at junction with notothyrial platform, becoming broader and higher anteriorly, rising to peak near middle of valve. Adductor muscle scars large, thickened. Platform occupies posteromedial half of shell floor, its edges finely crenulated, platform sides subparallel to shell margin and reentrant medially, joining at medial peak. Mantle canal system not well known; shell floor coarsely pustulose.

Ventral valve has short wide teeth; dental plates

obsolescent, reduced to thickenings at sides of muscle field. Thickened shell at apex of delthyrial cavity pierced by thin foramen. Muscle scars short, diductors slightly longer than adductor track. Platform of ventral valve like that of dorsal valve in location on shell floor and crenulation of edges; platforms of opposing valves overlap, that of ventral valve lying just inside that of dorsal valve except near middle of shell, where thickened margin of ventral platform merges with pair of deep grooves separated from each other by low median ridge. Mantle canals not impressed.

*Discussion.* This monotypic genus is erected to contain the type species *C. diaphragma* n. sp., described below. Its affinity with the leptellinids, apparent externally, is confirmed by internal features of both valves, and the high median elevation of the platform of its dorsal valve links it with the subfamily Leptellininae. Like *Anoptambonites* Williams (1962), it has a complete chilidium, an apically perforate pseudodeltidium and similarly folded shells, but the cardinalia of *Calyptolepta* are more like those of *Leptellina* Hall and Clarke (1892); the latter genus has an apparently imperforate pseudodeltidium and chilidial plates (Ulrich and Cooper, 1938, p. 187). The ventral musculature of *Calyptolepta* is leptellinid but, unlike any previously described leptellinid, the ventral valve bears a platform that corresponds to that of the dorsal valve.

Among the leptellinids, ventral valves that bear a counterpart of the dorsal platform are rare, confined to a few Silurian species of *Leangella*. Havlíček (1961) separated *Tufoleptina* (type: *T. tufogena* Havlíček) from *Leangella* based on its occurrence, but Cocks (1970, p. 157) pointed out that Ópik (1933, Pl. 8, fig. 6) had illustrated a ventral valve with a "submarginal ridge" in a topotype specimen of the type species of *Leangella*, *L. triangularis* (Holtedah).

The function of dorsal platforms has been interpreted in three ways: as a visceral disc marking the edge of the visceral cavity (Hall and Clarke, 1892, p. 293); as a platform supporting the lophophore (Williams and Rowell in Williams, *et al.*, 1965, p. H105); and as a submarginal rim bounding the brachial cavity (Havlíček, 1967, p. 15).

Grant's (1972) study of the feeding mechanism of productid brachiopods confirms the interpretation of the dorsal platform as a lophophore support. His illustration of a living *Thecedallina* shows its lophophore lying along a pair of curved ridges at the sides and front of the dorsal valve (1972, Pl. 5, fig. 21). He noted (1972, p. 228) the similarity of immature thecideans to the adult Permian productid *Cooperina inexpecta* Termier, Termier and Pajaud, which has brachial ridges remarkably like the platform of *C. diaphragma*.

### *Calyptolepta diaphragma* new species

Pl. 6, figs. 5-18

*Diagnosis.* Sulcate *Calyptolepta* having parvicostellate ornament of strongly contrasting stronger and weaker costellae, about 4 weaker ones between the stronger.

*Material.* Holotype: articulated valves, internal mould and part of external mould, GSC 35066. Paratypes figured and

measured: one articulated specimen, GSC 35067; 2 dorsal valves, internal moulds, one with counterpart external mould, GSC 35068, 35069, one external mould, 35070; 3 ventral valves, internal moulds, one with counterpart external mould (not figured), GSC 35071, 35072 and 35073. Paratypes measured but not figured: one articulated specimen, internal mould and part of external mould, GSC 35067, 2 dorsal valves, internal moulds, one with external counterpart, GSC 35074 and 35075, and one ventral valve internal mould, GSC 35076. Paratypes not figured or measured: 7 articulated specimens, 19 dorsal valves and 42 ventral valves, internal moulds, external moulds, or both.

### Measurements

GSC no.	Length				Hinge width
	overall	platform	muscle field	interarea	
(mm)					
Articulated shells					
holotype					
35066	9	v-6.0 d-5.0	1.50 2.50	2.00 0.75	14 —
paratype					
35067	v-10 d- 8	— —	— —	2.00 0.75	— 12
Dorsal valves					
paratype					
35068	7	4.0	2.75	0.80	16
paratype					
35069	8	—	—	0.75	—
paratype					
35070	7	5.0	3.50	0.75	10 (11)
paratype					
35074	9	6.0	3.50	0.80	17
paratype					
35075	9	6.0	4.00	1.00	12 (16)
Ventral valves					
paratype					
35071	8	5.5	1.50	1.50	15
paratype					
35072	9	6.0	1.50	1.50	10 (12)
paratype					
35073	10	5.5	1.80	2.00	13
paratype					
35076	10	5.5	2.00	2.00	11

( ) Estimate. v Ventral valve. d Dorsal valve.

*Description.* Shell length about two-thirds hinge width, cardinal extremities acute to slightly alate, sides anteriorly convergent, front broadly rounded. Apsacine ventral interarea about one-fifth shell length, about twice the length of the hypercline to anacline dorsal interarea; delthyrium and notothyrium narrow, both with complete covers. Sulcus of concave dorsal valve well defined, broadening anteriorly to include about a third of shell circumference; posterolateral sectors flared. Ventral valve has corresponding fold, with posterolateral sectors hollowed; anterior commissure broadly sulcate. About 7 stronger costellae per 5 mm at front of shells 8 to 10 mm long, with 3 to 5 much weaker costellae between them. Concentric ornament obscure except for a few irregularly spaced growth lines on anterior half.

Dorsal interior has long oval anteriorly expanding adductor muscle scars of thickened shell, separated by median ridge that rises to high crest in middle of valve. Scars extend to about two-thirds distance between posterior shell margin and margin of platform. Platform subparallel to anterolateral shell margin, about two thirds of shell length except in medial sector where it curves onto crest of median ridge; platform margin crenulated except in re-entrant medial sector. Mantle canals seen only between platform and shell edge where distal branches are widely spaced.

Ventral muscle field short, about a fifth of shell length, and about one-third wider at front than long; adductor scar about a third of total field width at its front, set slightly below diductor scars; anterior margins of both slightly thickened. Shell floor in front of adductor scar an elongate shallow depression that merges anteriorly with low median ridge flanked by pair of rounded anteriorly expanding grooves. Platform as on dorsal valve, subparallel to anterolateral margins about two thirds of shell length, except in re-entrant medial sector where platform margins curve into submedial grooves.

*Discussion.* Features that characterize *C. diaphragma* and the genus based on it include its chilidium, its apically perforated pseudodeltidium, its simple cardinal process and the platform on its ventral valve, a combination of characteristics not seen in any other leptellinid. The folding of the valves and the contrasting strength of costellae and their spacing are reasonably consistent among the specimens of the suite under study, and probably the features to be compared at the specific level, should congeners be discovered.

#### Subfamily LEPTESTIININAE Havlíček, 1961

##### Genus *Anechophragma* new genus

*Diagnosis.* Similar to *Leangella* Öpik but with multicostellate ornament; in dorsal valve cardinal process simple, brachio-phores subparallel to hingeline without definite terminations, inner platform raised anteriorly, supported by pair of submedian septa that extend beyond it to outer platform; in ventral valve dental plates lacking, muscle field wide, weakly impressed, counterpart of outer platform of dorsal platform present.

*Derivation of the name.* Greek *anecho* (raised) + *phragma* (plate)

Type species and only species assigned. *Anechophragma rarum* new species, described below

*Description.* Small, subtriangular to semielliptical, shallowly concavoconvex. Interareas short, ventral apsacline, with pseudodeltidium, dorsal hypercline, less than half length of ventral interarea; notothyrium bordered by short chilidial plates. Curvature of shells nearly uniform, lacking fold and sulcus. Ornament multicostellate, costellae wide, low, of uniform strength.

Dorsal interior has short simple bladelike cardinal process that rises from shell floor; brachio-phores short, low,

with short anteriorly directed projections, curved posteriorly toward posterior shell wall enclosing shallow sockets. Posteromedial third of shell floor occupied by structure considered here to be adductor muscle platform (also referred to in descriptions of *Leangella* as: *Brachiallamellen* by Öpik, 1933, p. 75; brachial lamellae by Spjeldnaes, 1957a, p. 82; lophophore platform by Muir-Wood and Williams in Williams, *et al.*, 1965, p. H378; visceral area by Havlíček, 1967, p. 15; platform by Cocks, 1970, p. 145) of thickened shell outlined at sides and front by undercut rim, medially re-entrant and peaked; median ridge of platform with low groove fades rapidly posteriorly to extinction in front of cardinal process. Paired anteriorly divergent submedian septa define sides of re-entrant segment of platform; lobes of platform anteriorly extend to points along septa, beyond which septa are reduced but continue to 'subperipheral rim'. Subperipheral rim of undercut shell subparallel to anterolateral shell margin at about two-thirds shell length, considered here to be lophophore platform.

Ventral valve interior almost featureless: no dental plates; muscle scars impressed only on posterior shell wall where outer sides of diductor scars are widely spaced. Subperipheral rim sharp-crested, coincident with and just within that of dorsal valve.

*Discussion.* This monotypic genus is erected to contain the type species *A. rarum* n. sp., described below. This species is based on only 5 specimens, in which some features cannot be observed. What is known of the species indicates that, despite its similarities to *Leangella* Öpik (1933), differences warrant their discrimination as distinct genera. The interiors of the dorsal valves of the two genera are similar but differ in the following details: (a) the posterior face of the cardinal process of *Anechophragma* is simple, lacking the lateral ridges of *Leangella*; (b) the brachio-phores of *Anechophragma* curve posteriorly and lack the anteriorly directed terminations seen in *Leangella*; (c) *Anechophragma* has long submedian septa, which are either short or lacking in *Leangella*; and (d) the subperipheral rim in *Anechophragma* is uniformly curved, parallel to the shell margin, whereas in most species of *Leangella* (but not *L. tufogena* Havlíček) it is projected forward near the middle. Inside the ventral valve, the differences are greater: *Leangella* has thick dental plates and a thickened muscle field, whereas *Anechophragma* has no dental plates and weakly impressed musculature. Although externally alike in shape and size, the ornament of *Anechophragma* is uniformly costellate rather than parvicostellate.

No features can be discerned among the Middle Ordovician species of *Leangella* or *Diambonia* (Spjeldnaes, 1957a; Williams, 1962) to indicate that they are transitional between *Anechophragma* and typical Silurian *Leangella*. Havlíček (1967, p. 33) suggested that the submarginal ridge on the ventral valve was a phylogerontic characteristic, but its presence on *Anechophragma* suggests otherwise.

The septa of the dorsal valve of *Anechophragma* and its multicostellate ornament suggest that it is also related to *Isophragma* Cooper (1956, p. 733) from the Middle Ordovician of North America. Although that genus does not have platforms on its shell floor, some specimens have thickened adductor muscle scars (*I. biseptatum* Cooper

(1956, Pl. 171, figs. 31, 32)), whose size and configuration resemble the adductor platform of *Anechophragma*. Other specimens in 3 of the 6 species described by Cooper have thickened peripheral rims on ventral valves, but none of these is as sharply defined as the rim of *Anechophragma*, and none has a comparable rim on the dorsal valve.

The interpretation of the elevated platform in the posterior part of the shell floor of the dorsal valve as an elevated adductor muscle platform is also indicated by a comparison of the dorsal valves of *Anechophragma* and *Calyptolepta*, described above. In the discussion of *Calyptolepta* the undercut ridge toward the front of the dorsal valve was interpreted as a lophophore support. Adductor muscle scars in the posterior third of that valve in *Calyptolepta* are thickened callosities. The ventral valves of both genera have similar submarginal ridges peripheral to counterpart ridges of the dorsal valves. Most likely the similar-appearing ridges, similarly placed near the shell margin of both valves in both genera, performed the same function of lophophore support. The location of the inner platform of *Anechophragma* in the same position as the adductor callosities of *Calyptolepta* also suggests identical function. Elevated platforms that were the seats of adductor muscles are not common among other Ordovician brachiopods but occur in this assemblage in *Progonambonites* sp.

*Anechophragma rarum* new species

Pl. 5, figs. 22–25

*Diagnosis.* *Anechophragma* with ornament of 5 to 7 low rounded costellae per mm at the front of specimens about 5 mm long.

*Material.* Holotype: dorsal valve, internal mould and part of external mould, GSC 35077. Paratype: articulated internal mould and counterpart dorsal external mould with inter-

areas, GSC 35078. Paratypes not figured or measured: 2 dorsal internal moulds, 1 ventral internal mould.

*Description.* Small shells, dorsal valve slightly concave, ventral valve moderately convex, subtriangular outline, widest at hinge, cardinal extremities acute, alate. Hypercline dorsal interarea about one-third length of short apsacline ventral interarea. Posterior of external mould of articulated specimen preserves imprint of very thin posterior face of cardinal process and flanking chilidial plates on thin curtain of matrix that fills space between convex pseudodeltidium and floor of dorsal valve.

Dorsal interior depressed at seat of cardinal process, no notothyrial platform; brachiophores posteriorly confined (extend into shell only about 0.25 mm), low round-topped thickened ridges that curve posteriorly, enclosing shallow sockets and merging with posterior shell wall about 1.5 mm beyond midline. Adductor muscle platform occupies postero-medial third of shell floor, outline resembles W, with grooved median ridge that rises anteriorly to undercut crest at medially re-entrant segment of platform; platform sides of slightly thickened shell posteriorly in front of lateral termination of brachiophores, sides converge slightly anteriorly, gradually thickening and rising above shell floor, meeting front at obtuse-angled anterolateral corners, beyond which platform tapers, to points along submedian septa; medial segment of platform between septa is re-entrant, raised to crest about opposite angular bend at its sides. Submedian septa diverge anteriorly at about 15°, highest at re-entrant segment of muscle platform, diminishing anteriorly to termination at lophophore platform. Lophophore platform nearly parallels anterolateral shell margin at about two-thirds shell length, sharp-edged at sides from its junction with posterior shell wall, becoming undercut towards front. Detail of shell floor texture not preserved.

Ventral interior has slight shell thickenings in place of dental plates, about 1.5 mm from shell midline; teeth not seen; muscle scars impressed only on posterior shell wall. Subperipheral ridge parallel to lophophore platform, just inside it, as seen on articulated internal mould.

*Measurements*

GSC no.	Length				Width	Costellae (per mm)
	overall	adductor muscle platform	lophophore platform/subperipheral ridge	interarea		
Dorsal valve holotype 35077	6	2	4.50	—	7 (12)	5
Articulated valve paratype 35078	4	2	d-3.50 v-3.25	.1 .3	11	7

( ) Estimate. d Dorsal valve. v Ventral valve.

*Discussion.* Although only 5 imperfect specimens are available, the assemblage of characteristics in this species is unique: shallow concavoconvex profile, multicostellate ornament, dorsal valve like *Leangella* but with a cardinal process lacking subsidiary ridges and a pair of long submedian septa, and a ventral valve virtually featureless except for its subperipheral ridge. The shell structure is presumably pseudopunctate but the pustulose internal surface characteristic of pseudopunctate shells is not impressed on these specimens.

Family BIMURIIDAE Cooper, 1956

Genus *Bimuria* Ulrich and Cooper, 1942

aff. *Bimuria* sp.

Pl. 6, figs. 30–34

Thirty-five specimens of deeply concavoconvex, smooth shells from Virgin Arm are ascribable to this genus but for their wide hinge: internal moulds of three articulated valves, four dorsal valves and 21 ventral valves, some with counterpart external moulds, and seven external moulds of dorsal and ventral valves.

*Description.* Small, wide-hinged, deeply concavoconvex shells, subtriangular in outline, hinge width nearly twice shell length; cardinal extremities extended, alate. Ventral interarea slightly concave, apsacline, with convex pseudodeltidium, about twice as long as hypercline dorsal interarea; chilidium present. Dorsal valve has depressed beak, deeply concave near middle; ventral valve has prominent beak perforated by small foramen, midpart highly arched, posterolateral slopes gently concave; anterior commissure rectimarginate. Shell surface nearly smooth, lacks radial ornament but has irregularly spaced very fine growth lines.

Dorsal interior has low simple bladelike cardinal process that rises directly from posteriorly sloping shell floor, its posterior face seen in external moulds as a thin groove. Brachiophores short, widely divergent, their diminished distal continuations curved posteriorly to include wide shallow sockets. Shell floor slightly depressed in front of cardinal process between brachiophores. Median septum rises from this depression, extends about two-thirds shell length, highest near middle.

Median septum flanked by pair of subtriangular platforms (lophophore platforms) that widen and thicken anteriorly, their anterior ends about coincident with that of median septum. Mantle canal system not seen; shell surface beyond platforms finely striated.

Ventral interior has wide short teeth; no dental plates. Muscle scars impressed only on sides of delthyrial cavity. Filling of foramen seen as tube at apex of delthyrial cavity in some specimens. Mantle canal system not known; much of shell floor finely striated.

*Measurements*

GSC no.	Length			Width
	total	platform	interarea	
			(mm)	
35079	3.0	1.75	—	4.0 (5)
35097	1.5 (2.5)	1.50	—	4.5
35080	5.0	—	—	9.0
35081	6.5	—	—	8.0 (12)
35082	4.0	—	d-0.5 v-1.0	8.0 (10)

( ) Estimate. d Dorsal valve. v Ventral valve.

*Discussion.* The interior of both valves of this species clearly shows features characteristic of *Bimuria*, especially the long subtriangular platforms and the median septum of the dorsal valve and the weakly impressed musculature of the ventral valve together with its umbonal foramen. Shape and ornament exclude it from *Bimuria*, however, as *Bimuria* is defined (Ulrich and Cooper, 1942, p. 622; Cooper, 1956, p. 764) as having a semielliptical to semicircular outline and an ornament of growth lamellae beyond its smooth umbonal region, whereas this species is subtriangular with a hinge width about twice shell length, and it is devoid of growth lamellae.

Two unidentified plectambonitids

Two different dorsal valves in the assemblage are each single representatives of taxa that must remain unidentified in the absence of additional specimens, especially counterpart ventral valves. They are briefly described insofar as the specimens permit, and their possible taxonomic affinities are indicated.

Unidentified plectambonitid *a*

Pl. 5, fig. 19

Specimen GSC 35083 is an articulated internal mould with associated ventral external mould, exposing the dorsal interior and a small part of the ventral exterior. Shell is deeply concavoconvex, outline subtriangular, hinge width (5 mm) more than twice shell length (2 mm); ornament finely costellate. Dorsal interarea short, anacline, notothyrium covered by chilidium. Cardinal process very short, simple, seen as groove on matrix filling between chilidium and shell floor. Brachiophores poorly preserved, probably short, curved posteriorly. Valve floor has pair of long septa that originate near base of cardinal process, diverge at about 10° and reach nearly to anterior shell margin. Ventral interior not known.

The long narrowly divergent septa of this specimen suggest affinities with *Syndielasma* Cooper.

Unidentified plectambonitid *b*

Pl. 5, figs. 20, 21

A fairly complete dorsal internal mould and its counterpart external mould (GSC 35084) indicate a small concave parvicostellate shell that has a wide low fold. Outline trapezoid-auriculate, widest at hinge (preserved 6 mm; estimate of original 9.5 mm), more than twice the length (3.5 mm). Cardinal extremities extended, sharply acute, sides moderately convergent, broadly rounded, front broad, nearly parallel to hinge, slightly recessed at fold. Interarea very short, hypercline; notothyrium probably open. Profile nearly flat posteromedially, becoming moderately concave toward middle and increasingly concave toward front so that shell slope near anterior margin is nearly at right angle to posterior part of shell. Fold originates at about one-third shell length; sides of fold include angle of about 60°; fold at front of shell is well defined low arch that occupies about half of broad front of shell. Ornament imperfectly preserved; parvicostellate pattern best preserved in troughs to sides of fold where major costellae, about 0.75 mm apart, include 5 minor costellae. Parvicostellate pattern less well developed on fold, where about 9 stronger costellae alternate with single weaker ones. Fine growth lines on costellae and interspaces closely spaced near shell margins.

Interior has simple bladelike cardinal process that rises directly from shell floor. Brachiophores short, posterolaterally curved, enclosing small sockets. Shell floor symmetrically divided by anterolaterally expanding depression that corresponds with external fold on which no structures are impressed. Higher parts of shell on either side occupied by pair of anteriorly expanding ovoid platforms subdivided by pair of transverse posterolaterally directed ridges, posterior deeper than anterior, probably adductor muscle scars, and the anterior parts, about 1 mm from shell margins, probably lophophore support platforms.

This specimen resembles dorsal valves identified by Cooper (1956, Pl. 221, figs. 13–15) as immature *Christiana subquadrata* (Hall) from the Pratt Ferry Formation, Alabama. Cooper (*oral commun.*, July 1973) has also obtained such shells from the “sponge bed” of the Antelope Valley Limestone, Ikes Canyon, Nevada. It is now apparent that these brachiopods belong to a yet undescribed genus of plectambonitaceans. Although their dorsal valves resemble this specimen, the lack of a ventral valve defers its positive identification with them.

Order *PENTAMERIDA* Schuchert and Cooper, 1931Suborder *SYNTROPHIDINA* Ulrich and Cooper, 1936

Superfamily PORAMBONITACEA Davidson, 1853

Family PORAMBONITIDAE Davidson, 1853

Genus *Rugostrophia* Neuman, 1971*Rugostrophia* Neuman, 1971, p. 118

*Revised diagnosis.* Dorsibiconvex, gibbous, with subequal interareas, a high dorsal fold and corresponding ventral

sulcus, elliptical outline, wider than long, widest near middle, ornament costellate to reticulate; dorsal interior has short discrete brachiophore-supporting plates, cardinal process absent, adductor muscle scars distinct, quadripartite, the rear part of the anterior pair between the posterior pair; ventral valve has stout dental plates, advancing at their bases to form pseudospondylium.

Type species. *R. sylvestris* Neuman, 1971, p. 119, 120, Pl. 2, figs. 1–11

Species assigned. *R. latireticulata* new species, described herein; *Porambonites* (s.s.) sp. Bates, 1968, p. 177, Pl. 11, figs. 1–6, 8

*Discussion.* This genus is redefined to include *R. latireticulata* n. sp., described below, whose internal features are essentially the same as those of *R. sylvestris* but whose coarse porambonitid ornament is not provided for in the original description of the genus. Restudy of the type suite of this species shows that its ornament was incorrectly described as costate; it should have been described as costellate, about 12 costellae per 5 mm, with growth lines of about the same spacing on parts of some specimens, filling interspaces and producing a coarsely reticulate porambonitid pattern.

*Porambonites* (s.s.) sp. of Bates (1968, p. 177, figs. 1–6, 8) is also assigned to the genus. Illustrated specimens of its dorsal valve have short discrete brachiophore-supporting plates, no cardinal process and an array of adductor muscle scars like that of *Rugostrophia*. Additional specimens of this species collected by Bates and myself in 1971 include external moulds with about 15 costellae per 5 mm and somewhat more widely spaced growth lines that fill interspaces on some parts of the shell where the ornament is porambonitid; an internal mould in the additional collection has a pseudospondylium that is preserved somewhat differently from one illustrated by Bates.

In both *R. sylvestris* and the “*Porambonites*” of Bates, the radial ornament is more persistently preserved than the concentric ornament, and the reticulate pattern is visible on only parts of external moulds. In *R. latireticularis*, however, the coarse reticulate pattern is apparent in all external moulds in the suite of specimens examined.

*Rugostrophia* is more closely related to the Porambonitidae than to the Huenellidae with which it was originally classed but it is distinct from any of the three subgenera of *Porambonites* recognized by Amsden and Biernat (*in Williams, et al.*, 1965, p. 532, 533).

Externally similar shells of this kind appear to have considerably diverse internal structures but only a few specimens have been illustrated that give any indication of their interiors. Greatest detail was given by Noetling (1883) for *P. (EQUIROSTRA) schmidti* and *P. (E.) bauri* in original descriptions of those species. The posterior view of a specimen of *P. intercedens* Pander given by Teichert (1930, Pl. 11, fig. 7) shows different structures; in its dorsal valve are the bases of anteriorly divergent brachiophore-supporting plates, and in the ventral valve is the base of a median septum that presumably supports a spondylium. These features suggest syntrophopsid affinities, comparable to *Cuparius* Ross (1971). “*Triplecia*” *norvegica* Reed (*in Kiaer,*

1932, Pl. 11, fig. 12b), obviously more a porambonitid than a tripleciid, has a different arrangement of plates on the shell floors, with a pair of subparallel dental plates in the ventral valve and a median septum in the dorsal valve, which suggests that a cruralium is present.

The presence or absence of a cardinal process is also unsettled. Schuchert and Cooper (1932, p. 102) stated that a cardinal process is absent from the genus *Porambonites*. Spjeldnaes (1957b, p. 218), however, showed by means of serial sections that there is one in *P. (Porambonites) reticulatus* Pander, and he called attention to the "small median ridge between the socket plates" of *P. (Equirostra) schmidti* Noetling in the photograph of a silicified specimen of that species published by Schuchert and Cooper (1932, Pl. 14, fig. 21). A cardinal process is also shown in serial sections of *P. (Noetlingia) tscheffikini* de Verneuil by Hall and Clarke (1894, p. 229).

The lack of a cardinal process and the short subparallel brachiophore-supporting plates distinguish *Rugostrophia* from other described porambonitids. In its transverse shape, well developed interareas and relatively coarse ornament, it resembles *P. (Noetlingia)*.

### *Rugostrophia latireticulata* new species

Pl. 7, figs. 1–8

*Diagnosis.* Large, transversely elliptical *Rugostrophia* having a coarse reticulate ornament, the costellae more widely spaced than the concentric laminae.

*Derivation of the name.* Latin *latus* (broad) + *reticulata* (netlike)

*Material.* Holotype: dorsal valve, internal mould and counterpart external mould, GSC 35085. Paratypes figured and measured: dorsal valve, internal mould, GSC 35086; ventral valve, internal mould and counterpart external

mould, GSC 35087. Paratypes figured but not measured: ventral valve, internal mould, GSC 35089; ventral valve, external mould, GSC 35088. Paratypes neither figured nor measured: internal moulds of 8 dorsal valves, 10 ventral valves, most with some of their counterpart external moulds, and 4 fragmentary external moulds.

*Description.* Large, dorsibiconvex, elliptical outline, about one-fifth wider than long, widest near middle; cardinal extremities obtuse, rounded, sides having smaller radius of curvature than front. Interareas on both valves, that of ventral valve apsacline, about as long as orthocline dorsal interarea; delthyrium and notothyrium open. Dorsal valve higher than ventral valve, dorsal beak high, merging anteriorly into highly arched fold; posteroventral slopes somewhat concave. Ventral beak lower than that of dorsal valve, passing anteriorly into sulcus at about 5-mm shell length, fold and sulcus both becoming well defined, with steep sides and rounded crest and trough, respectively, at about midlength. Lateral commissures straight, anterior commissure strongly uniplicate, the plication having steep sides and broadly rounded crest and trough. Ornament reticulate, formed of costellae and thick growth lines in interspaces, the latter more closely spaced than the former, pits between them wider than long. Costellar spacing nearly uniform through shell length, increasing by insertion in interspaces, more closely spaced (about 9 per 5 mm) on fold and sulcus than on flanks (about 5 to 7 per 5 mm). Concentric ornament forming front and back walls of pits spaced at 10 to 14 per 5 mm. Growth lamellae crowded near shell margins.

Dorsal interior has deep notothyrial cavity, about one-fifth shell length, bordered by stout brachiophore-supporting plates. Floor of notothyrial cavity spoonlike, smooth, without trace of cardinal process, median elevation or depression; shell slightly thickened between anterior ends of bases of brachiophore-supporting plates. Bases of brachiophore-supporting plates subparallel at sides of notothyrial platform; inclination of plates variable, from vertical to divergent upward at steep angles, flaring outward distally and tapering to blunt terminations of triangular cross-section. Sockets

### Measurements

GSC no.	total		Length			Maximum width		Thickness	
	plan projection	circum- ference	notothyrial platform	interarea	hinge	plan projection	circum- ference	midlength	fold height
(mm)									
Dorsal valves									
holotype 35085	24	30	5	3.0	26	30	38	10	5
paratype 35086	19	23	5	2.5	17	24	36	8	5
Ventral valve									
paratype 35087	24	28	10	—	25	28 (30)	30 (32)	4	3

( ) Estimate.



are shallow excavations on posterior faces of brachiophores. Adductor muscle scars large, quadripartite, radially striated, of thickened shell, forming a triangular field whose apex is near shell middle; posterior pair widely separated, back half of anterior pair lying between them. Shell margins thickened. Shell floor smooth, without impressions of mantle canals or external ornament.

Ventral interior has long pseudospondylium, about one-third shell length, bordered by strong ventrally convergent advancing dental plates. Pseudospondylium elliptical in outline, widest near middle, about 3 times greater than width at narrowly rounded, thickened anterior margin. Adductor track wide, about half width of pseudospondylium at its widest, extends beyond diductor scars to anterior margin of pseudospondylium; diductor scars set slightly below adductors, with tapered terminations at about two-thirds length of pseudospondylium. Saccate mantle canal system impressed as ridges in posterior half of shell floor; *vascula media* indicated by pair of subparallel septumlike ridges that extend forward from about midlength of pseudospondylium; *vascula genitalia* marked by as many as 7 pairs of radial ridges on posterolateral part of shell floor. Shell floor smooth with thickened margin as on dorsal valve.

#### Porambonitid genus and species undetermined

Pl. 7, figs. 9–12

An internal and external mould of a dorsal valve (GSC 35090) of an undetermined porambonitid was obtained from the Village Cove locality and is described here for comparison with *Rugostrophia latireticulata*. Identification is deferred pending recovery of a ventral valve.

*Description.* Subhexagonal, slightly wider at midlength than long, narrow at hinge, narrowly rounded beak, and somewhat extended anteriorly at fold. Interarea very short, obsolete; moderately high, uniform convexity, highest near middle; fold wide and low. Ornament finely reticulate, more than 50 costellae per 5 mm; growth lines fill interspaces at about same spacing, forming very small, nearly equidimensional pits.

Interior has long, lathlike brachiophores; sockets floored by fulcral plates between brachiophore bases and posterior shell wall. Brachiophore-supporting plates slope steeply toward shell floor and are prolonged anteriorly, diminishing in height and diverging, their terminations at about one-third shell length; floor of notothyrial cavity smooth, without trace of cardinal process or lateral ridge. Adductor muscle scars and mantle canal system not impressed.

#### Measurements (mm)

Length—21

Length of brachiophore-supporting plates—6

Hinge width—16

Maximum width—23

Maximum thickness—3

Height of fold at anterior margin—1.5

*Discussion.* The obsolescent interarea of this specimen, its nearly equidimensional outline, low convexity, low fold and fine ornament clearly distinguish it from *Rugostrophia*. In these respects it is more like *Porambonites* (*Porambonites*), as are its long, divergent brachiophore-supporting plates. The lack of a cardinal process in this specimen remains a problem in assigning its genus, since Spjeldnaes (1957b, p. 218) observed one on *P. (P.) reticulatus* Pander. The absence of a ventral valve further hinders generic identification.

#### Family CAMERELLIDAE Hall and Clarke, 1894

#### Subfamily CAMERELLINAE Hall and Clarke, 1894

#### Genus *Camerella* Billings, 1859

*Camerella?* sp.

Pl. 7, figs. 22, 23

Internal moulds of 6 small ventral valves, 2 with parts of their counterpart external moulds, that have camerellid features are questionably assigned to this genus, but no dorsal valves were found to confirm this assignment.

*Description.* Small convex sulcate shells, smooth on posterior half, costate beyond, nearly round in outline, apical angle about 80°, sides and front broadly rounded, maximum width near middle. Profile broadly convex in posterior half; sulcus originates near middle, narrow and shallow at anterior margin, occupied by 3 costae; flanks swollen toward front, with about 5 costae diminishing in amplitude toward sides. Costae rounded, interspaces V-shaped; closely spaced growth lines seen only in troughs of interspaces.

Internal moulds have narrow spondylium, supported anteriorly by median septum. Spondylium about one-third shell length, narrow, widest at its middle, with pedicle callist at apex and tapering anteriorly to junction with median septum which continues to about midlength of shell. Mantle canal system not preserved; costation impressed on shell floor.

#### Measurements

GSC no.	Length			Max. width	Thickness
	overall	spondylium	median septum		
35091	4.5	1.5	2.0	4.5	1.75
35092	4.5	1.5	2.5	4.0	1.25

*Discussion.* Confident identification of these specimens is impossible without knowledge of the dorsal valve. Nevertheless their affinity to *Camerella* is suggested both by their internal features and because their costation is confined to the anterior half of the shell surface. *Camerella tumida* Cooper (1956, p. 582, Pl. 111, figs. 36–40), from the lower

to middle Table Head Limestone of western Newfoundland, a small shell similar in outline to these specimens, is the oldest species of the genus recorded.

Family SYNTROPHOPSIDAE Ulrich and Cooper, 1936

Genus *Rhysostrophia* Ulrich and Cooper, 1936

*Rhysostrophia?* sp.

Pl. 7, figs. 13–15

One costate, sulcate ventral valve and a similarly ornamented dorsal valve with a complementary fold have internal features that suggest they be assigned to this genus.

*Description.* Dorsal valve, an internal mould (GSC 35094), triangular, widest at hinge, about one-third wider than long; interarea incompletely preserved, short, orthocline, notothyrium open. Preserved cardinal angle acute, sides and front broadly rounded. Profile medially swollen; beak high, fold prominent, well defined sides forming angle of 40°; fold about 5 mm wide at front, bears 8 low rounded costae; lateral slopes moderately convex near middle, moderately concave posterolaterally. Brachial lamellae closely spaced (0.5 mm), short (1.5 mm), subparallel, converging slightly toward shell floor; brachiophores not seen; notothyrial cavity narrow, cardinal process lacking; median ridge short, a thickening of shell at front of notothyrial cavity.

Ventral valve, an internal mould and small fragment of its counterpart external mould (GSC 35093); outline subelliptical, wider than long, apical angle about 140°, maximum width at about one-third shell length, sides

narrowly rounded, front broadly rounded. Interarea short, apsacline; delthyrium open. Beak low, sulcus wide and deep, originating well back on shell, its sides including angle of about 90°; flanks swollen, high. Radial ornament of about 20 rounded costae at front of sulcus about 7 mm wide. Spondylium short, supported nearly its full length on median septum (2 mm long) that extends short distance beyond it.

*Measurements*

GSC no.	Maximum length	Maximum width
	(mm)	
Dorsal valve 35094	7	7 (11)
Ventral valve 35093	7	10 (13)

( ) Estimate.

*Discussion.* The two specimens described here are the only ones obtained from the Virgin Arm material that have internal structures of the syntrophopsids. The specimens are of about the same size and have similar ornament, but differences in outline and in the shape of the fold of one and the sinus of the other make it uncertain that the two are the tectonically deformed opposite valves of the same species.

Of the two specimens, the ventral valve preserves features most like *Rhysostrophia*. Its wide sulcus resembles that of *R. nevadensis* Ulrich and Cooper. The termination of its median septum just beyond the spondylium is comparable to the arrangement in silicified specimens from the Antelope Valley Limestone, Meiklejohn Peak, Nevada in the collections of the U.S. National Museum.

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Plate 1

*Orthisocrania* sp.

Figures 1, 2. Dorsal valve, internal and external moulds of the same specimen, GSC 34958;  $\times 1.5$ .

*Productorthis mainensis* Neuman (all at  $\times 2$ )

Figures 3, 4. Dorsal valve, internal mould and rubber replica; the full length of growth lamellae are preserved around the anterior margin of this specimen, GSC 34965.

Figures 5, 6. Dorsal valve, internal and external moulds of the same specimen, GSC 34966.

Figure 7. Dorsal valve, internal mould; beneath the slitlike impression of the cardinal process is the laterally expanded impression of the chilidium; GSC 34967.

Figure 8. Ventral valve, internal mould, GSC 34970.

Figures 9, 10. Ventral valve, rubber replica and internal mould, GSC 34968.

Figures 11, 12. Ventral valve, internal and external moulds of the same specimen, GSC 34969.

*Orthambonites* sp. (all at  $\times 1.5$ )

Figures 13, 14. Dorsal valve, internal and external moulds of the same specimen, GSC 34959.

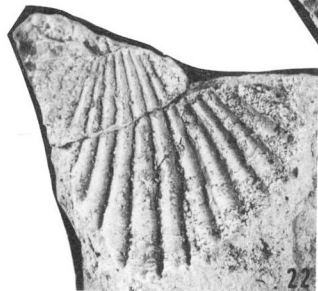
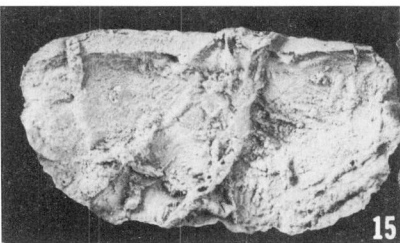
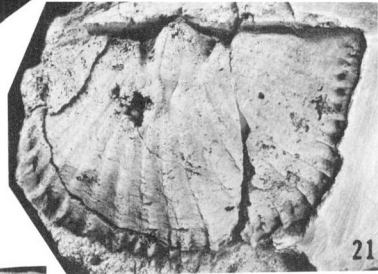
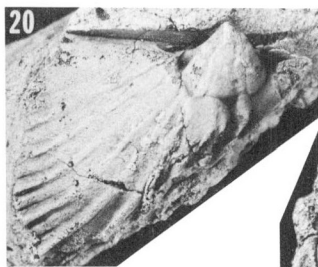
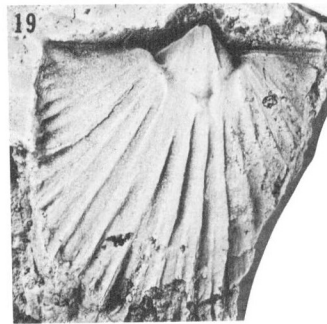
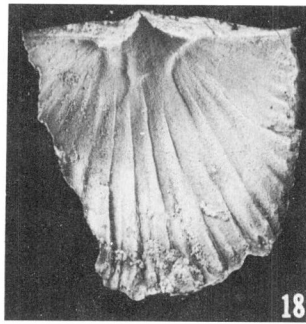
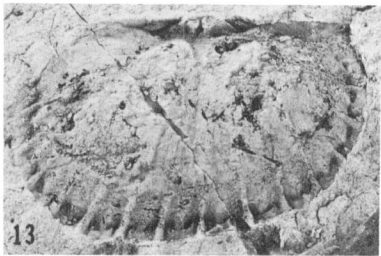
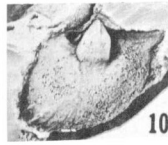
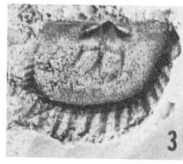
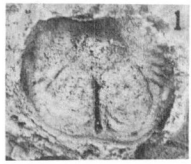
Figures 15, 16. Dorsal valve, rubber replica and internal mould, GSC 34960.

Figure 17. Dorsal valve, external mould; very fine striations on the costae and the growth lines are well preserved on this specimen, GSC 34961.

Figures 18, 19. Ventral valve, rubber replica and internal mould, GSC 34964.

Figure 20. Ventral valve, internal mould, details of musculature are well preserved, GSC 34963.

Figures 21, 22. Ventral valve, internal and external moulds of the same specimen, GSC 34962.



## Plate 2

*Glypteria* sp. (all at  $\times 5$ )

Figure 1. External mould showing dorsal valve and ventral interarea, GSC 34972.

Figures 2, 3. Dorsal valve, external and internal moulds of the same specimen, GSC 34974.

Figures 4, 5. Articulated internal mould, dorsal and ventral views, GSC 34971.

Figure 6. Dorsal valve, rubber replica of exterior and part of ventral interarea, GSC 35095.

Figures 7, 8. Ventral valve, external and internal moulds of the same specimen, GSC 34973.

*Platystrophia?* sp. (all at  $\times 1.5$ )

Figures 9, 10. Dorsal valve, internal mould, posterior and dorsal views, GSC 34981.

Figures 11, 12. Ventral valve, median segment of external mould and internal mould, GSC 34982.

*Plectorthis* sp. (all  $\times 2$  except fig. 18,  $\times 10$ )

Figures 13, 14. Dorsal valve, internal and external moulds of the same specimen; note that the fillings of the sockets are isolated by impressions of fulcral plates in the internal mould, and that exopunctae are spinelike fillings of matrix on the shoulders of finely striated costae on the external mould; GSC 34975.

Figures 15–17. Dorsal valve, internal mould, partial external mould, and rubber replica of interior, GSC 34978.

Figure 18. Small segment of anterior edge of dorsal internal mould showing filling of a puncta from floor of valve, GSC 34976.

Figures 19, 20. Ventral valve, internal mould and rubber replica, GSC 34979.

Figure 21. Ventral valve, internal mould, GSC 34980.

*Acanthorthis terreneuvensis* new genus, new species

(all  $\times 1.5$  except fig. 28,  $\times 5$ )

Figures 22, 23. Ventral valve, external and internal moulds; impressions of the spinose costellae are well displayed on the right-hand side of the external mould; holotype, GSC 34986.

Figures 24, 25. Dorsal valve, internal mould, dorsal and posterior views, paratype, GSC 34985.

Figures 26, 27. Ventral valve, external and internal moulds of the same specimen, paratype, GSC 34988.

Figure 28. External mould, oblique view, showing impressions of spines, GSC 34987.

*Virgoria virgensis* new genus, new species (all at  $\times 5$ )

Figures 29, 30. Articulated internal mould, dorsal and ventral views, holotype, GSC 34998.

Figures 31, 32. Articulated internal mould, dorsal and ventral views, paratype, GSC 34999.

Figures 33, 34. Articulated internal mould, dorsal and ventral views, paratype, GSC 35000.

Figure 35. Ventral valve, internal mould, paratype, GSC 35003.

Figure 36. Dorsal valve, external mould, paratype, GSC 35002.

Figure 37. Dorsal valve, internal mould, paratype, GSC 35001.

*Paurorthis* sp. (all at  $\times 2$  except figs. 38 and 39,  $\times 10$ )

Figures 38, 39. Small segments of anterior edges of internal moulds of a dorsal and a ventral valve, respectively, showing on each a matrix-filled puncta between internal and external surfaces, GSC 34992 and GSC 34994.

Figure 40. Ventral valve, internal mould, GSC 34996.

Figure 41. Ventral valve, internal mould, GSC 34995.

Figures 42, 43. Ventral valve, internal mould and rubber replica, GSC 34997.

Figures 44, 45. Dorsal valve, rubber replica and internal mould, GSC 34991.

Figure 46. Dorsal valve, internal mould, GSC 34993.

Figures 47, 48. Dorsal valve, internal and external moulds of the same specimen; fillings of punctae are small spines in the impressions of the costellae on the external mould; GSC 34990.

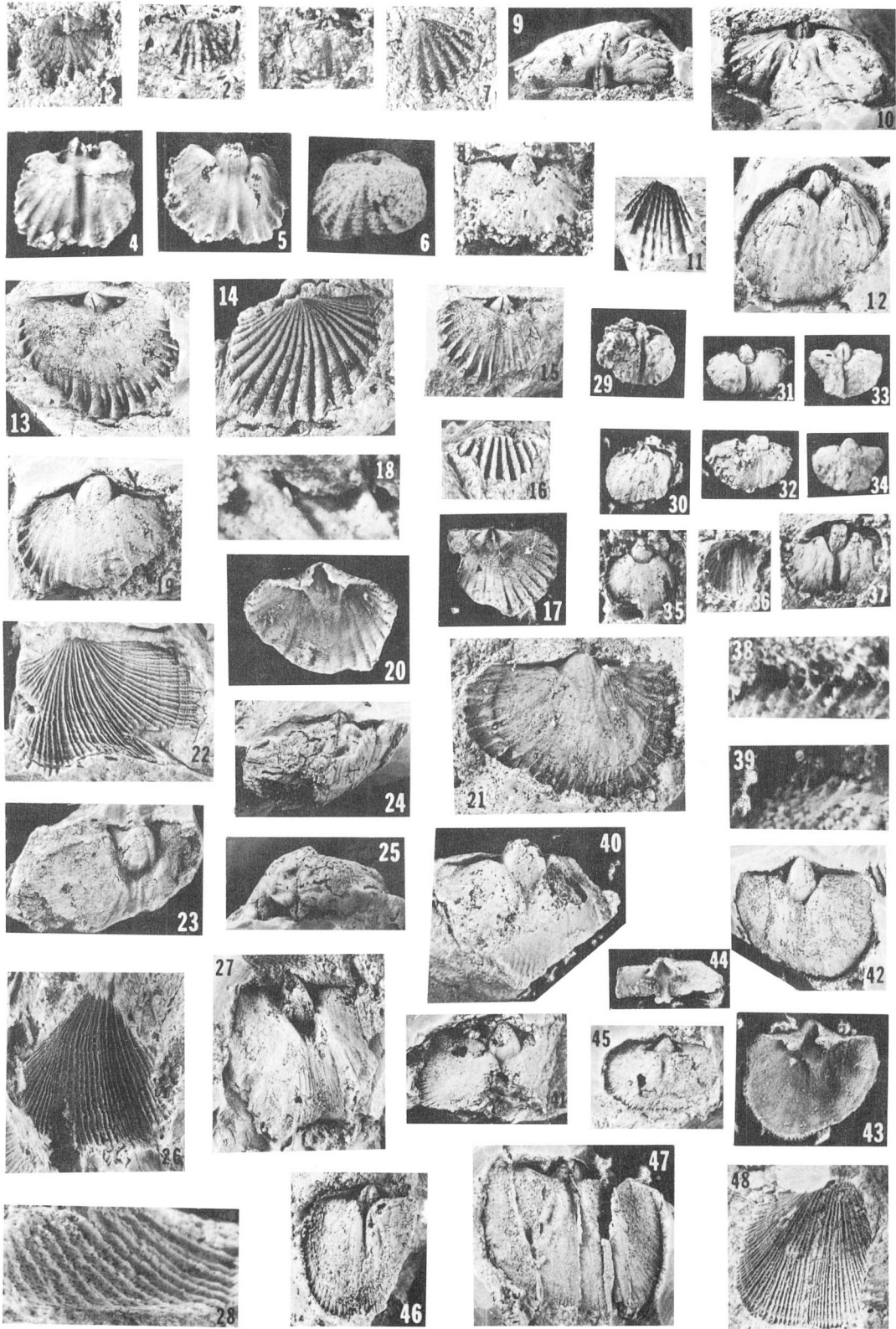




Plate 3

*Tritoechia billingsi* Neuman (figs. 1–4,  $\times 1.5$ , fig. 5,  $\times 3$ )

Figures 1–3. Ventral valve, internal and external moulds, and rubber replica of interior, GSC 35020.

Figure 4. Dorsal valve, internal mould, GSC 35019.

Figure 5. Ventral valve, external mould; closely spaced fine growth lamellae are visible at the bases of impressions of costellae; GSC 35021.

*Atelelasma atlanticus* new species (all at  $\times 2$   
except figs. 22, 23,  $\times 1.5$ )

Figures 6–8. Ventral valve, internal mould, partial external mould, and rubber replica of interior, paratype, GSC 35008.

Figures 9–11. Dorsal valve, internal mould, external mould, and rubber replica of exterior, holotype, GSC 35004.

Figures 12–14. Dorsal valve, partial external mould, rubber replica of interior, and internal mould, paratype, GSC 35005.

Figure 15. Dorsal valve, internal mould, paratype, GSC 35007.

Figures 16–19. Ventral valve, posterior view of external replica, posterior view of external mould, ventral view of external mould, and rubber replica of same; note the short plates bordering the delthyrium on this specimen (figs. 16 and 17), and another (fig. 20); paratype, GSC 35010.

Figures 20, 21. Ventral valve, rubber replica of posterior and external mould, paratype, GSC 35009.

Figures 22, 23. Dorsal valve, external mould, and rubber replica of exterior, paratype, GSC 35006.

*Ahtiella paucirugosa* new species (all at  $\times 1.5$ )

Figure 24. Dorsal valve, internal mould, paratype, GSC 35053.

Figures 25, 26. Articulated internal mould, dorsal and ventral views, paratype, GSC 35051.

Figures 27, 28. Articulated internal mould, dorsal and ventral views, paratype, GSC 35052.

Figures 29, 30. Dorsal valve, rubber replica of interior, and internal mould, paratype, GSC 35054.

Figures 31, 32. Ventral valve, external and internal moulds, holotype, GSC 35050.

Figures 33–35. Ventral valve, internal mould, rubber replica of posterior part of interior, and external mould, paratype, GSC 35055.

Figures 36, 37. Ventral valve, external and internal moulds, paratype, GSC 35056.

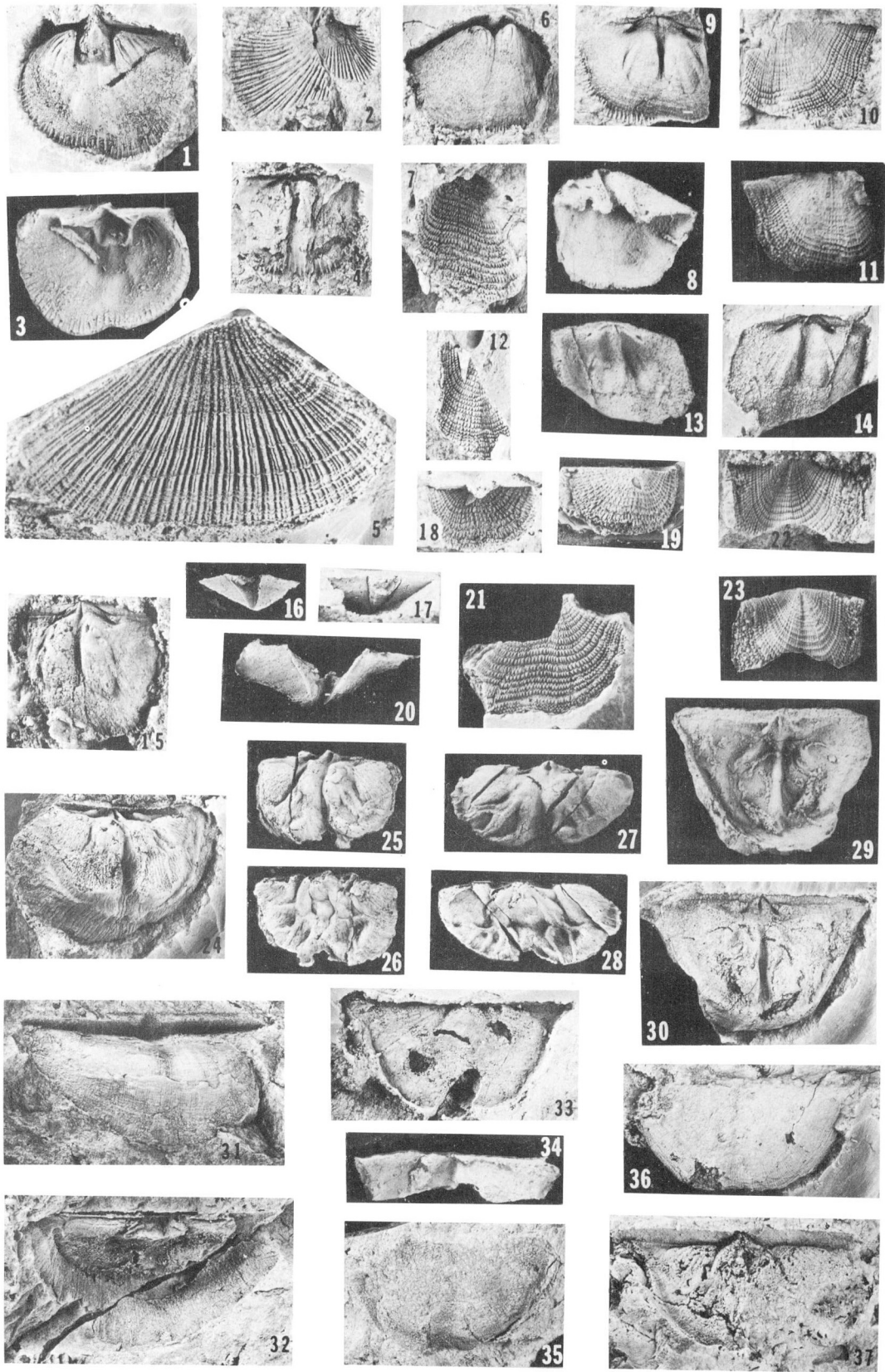


Plate 4

*Progonambonites* sp. (all at  $\times 1.5$ )

Figures 1–4. Ventral valve, internal mould, rubber replica of interior, external mould, and rubber replica of exterior, GSC 35016.

Figures 5, 6. Dorsal valve, internal mould and rubber replica, GSC 35012.

Figures 7, 8. Ventral valve, external mould and rubber replica, GSC 35017.

Figures 9, 10. Dorsal valve, internal and external moulds of the same specimen, GSC 35014.

Figure 11. Ventral valve, rubber replica of interarea, GSC 35096.

Figure 12. Dorsal valve, internal mould, GSC 35013.

Figures 13, 14. Ventral valve, internal mould, ventral and posterior views; impressions of the lateral septa are visible in the posterior view; GSC 35022.

*Antigonambonites* sp. (all at  $\times 1.5$ )

Figures 15, 16. Dorsal valve, internal mould and rubber replica, GSC 35033.

Figures 17–19. Dorsal valve, rubber replica of exterior, internal and external moulds, GSC 35031.

Figures 20, 21. Dorsal valve, internal mould and rubber replica, GSC 35032.

Figures 22, 23. Ventral valve, internal and external moulds, GSC 35036.

Figure 24. Ventral valve, internal mould, GSC 35034.

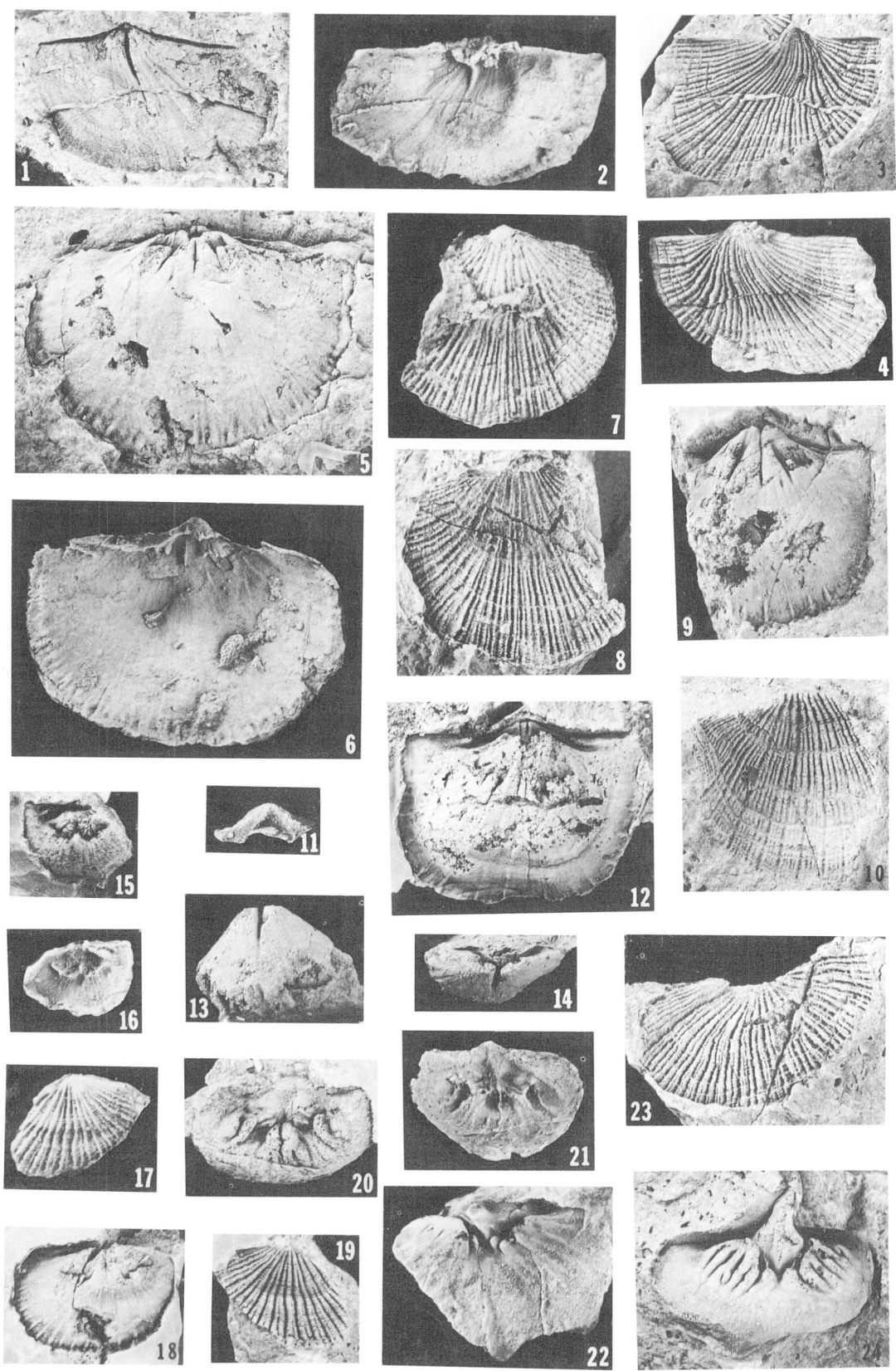


Plate 5

*Guttasella gutta* new genus, new species (figs. 1, 3–5 at  $\times 1.5$ ;  
fig. 2 at  $\times 3$ )

Figure 1. Ventral valve, internal mould, paratype, GSC 35059.

Figure 2. Ventral valve, partial external mould, paratype, GSC 35060.

Figures 3–5. Dorsal valve, external mould, internal mould, and rubber replica of posteromedial part of interior; although the external mould is largely uninformative, a segment of the deflected front margin is preserved; holotype, GSC 35058.

*Jaanussonites hornei* new genus, new species  
(figs. 9–14 at  $\times 1.5$ ; figs. 6–8, 15–18 at  $\times 2$ )

Figures 6, 7. Ventral valve, ventral and posterior views of a laterally compressed specimen, paratype, GSC 35027.

Figure 8. Ventral valve, internal mould, paratype, GSC 35029.

Figures 9, 10. Ventral valve, rubber replica of exterior, posterior and side views, paratype, GSC 35030.

Figures 11, 12. Dorsal valve, internal mould and rubber replica, holotype, GSC 35023.

Figure 13. Dorsal valve, internal mould, paratype, GSC 35026.

Figure 14. Dorsal valve, internal mould, paratype, GSC 35024.

Figures 15, 16. Ventral valve, external and internal moulds, paratype, GSC 35028.

Figures 17, 18. Dorsal valve, external and internal moulds; hollowness of costellae seen from spinelike threads of matrix rising obliquely from impressions of costellae; paratype, GSC 35025.

Unidentified plectambonitid *a* ( $\times 5$ )

Figure 19. Articulated specimen, internal mould of dorsal valve exposed, GSC 35083.

Unidentified plectambonitid *b* (both at  $\times 4$ )

Figures 20, 21. Dorsal valve, internal and external moulds, GSC 35084.

*Anechophragma rarum* new genus, new species (all at  $\times 3$ )

Figures 22, 23. Articulated specimen, ventral internal mould exposed, dorsal external mould after removal of internal mould, paratype, GSC 35078.

Figures 24, 25. Dorsal valve, rubber replica of interior and internal mould, holotype, GSC 35077.

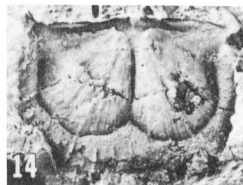
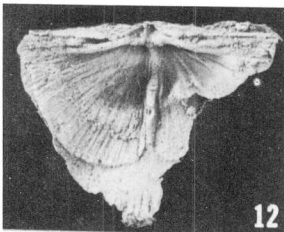
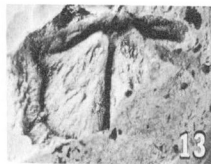
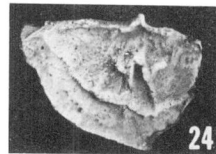
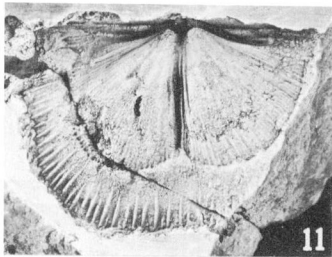
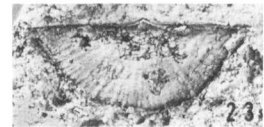
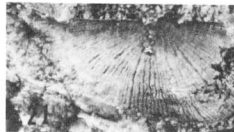
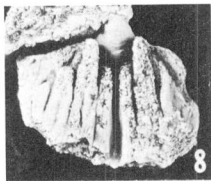
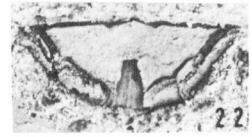
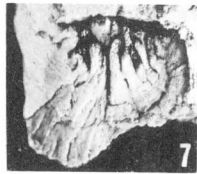
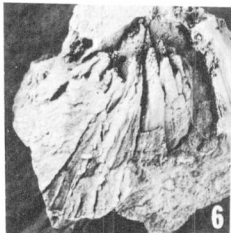
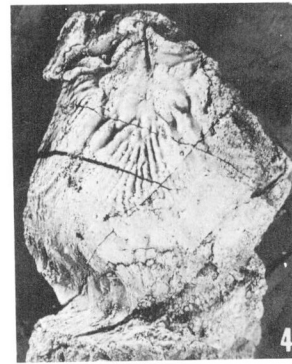
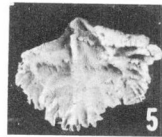
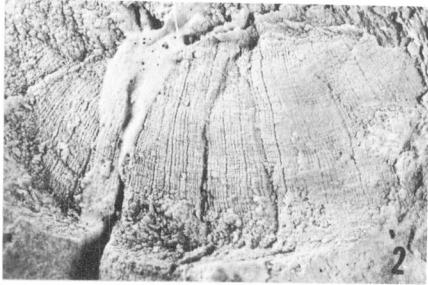
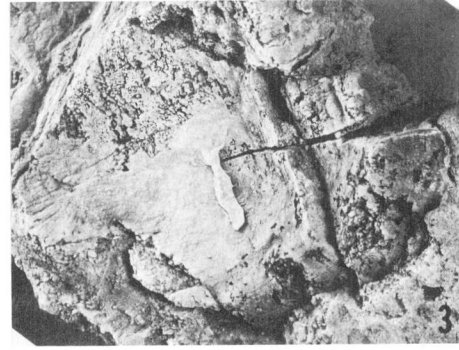
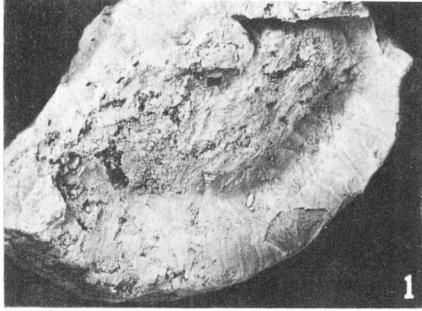


Plate 6

*Inversella* sp. (all at  $\times 1.5$ )

Figures 1, 2. Dorsal valve, internal and external moulds, GSC 35062.

Figures 3, 4. Ventral valve, internal and external moulds, GSC 35063.

*Calyptolepta diaphragma* new genus, new species (all at  $\times 2$ )

Figures 5, 6. Articulated valve, internal mould, ventral and dorsal views; overlap of the platform of the dorsal valve beyond that of the ventral valve can be seen in the relative positions of the impressions of the platforms at the broken mid-front of this specimen; the distance between the platform and the edge of the specimen is greater on the ventral valve than on the dorsal; holotype, GSC 35066.

Figures 7–9. Dorsal valve, external mould, rubber replica of interior, and internal mould, paratype, GSC 35068.

Figure 10. Dorsal valve, external mould, paratype, GSC 35069.

Figures 11, 12. Ventral valve, rubber replica of interior and internal mould, paratype, GSC 35071.

Figures 13, 14. Ventral valve, internal mould and rubber replica; a thread of matrix that filled the foramen extends back from the apex of the filling of the delthyrial cavity; paratype, GSC 35072.

Figure 15. Articulated specimen, external mould, dorsal view, paratype, GSC 35067.

Figure 16. Articulated specimen, view of ventral side of internal mould, paratype, GSC 35073.

Figures 17, 18. Dorsal valve, internal mould and rubber replica, paratype, GSC 35070.

*Ingria* sp. (all at  $\times 1.5$  except fig. 22 at  $\times 5$ )

Figures 19–21. Dorsal valve, internal and external moulds, and rubber replica of interior, GSC 35038.

Figure 22. Ventral valve, partial external mould showing impression of fine ornament, GSC 35043.

Figure 23. Dorsal valve, internal mould, GSC 35040.

Figure 24. Ventral valve, internal mould, GSC 35042.

Figure 25. Ventral valve, internal mould, GSC 35041.

Figures 26–28. Dorsal valve, internal mould, rubber replica of interior, and partial external mould, GSC 35037.

Figure 29. Dorsal valve, internal mould, GSC 35039

aff. *Bimuria* sp. (all at  $\times 3$ )

Figure 30. Articulated valves, internal mould, dorsal view, GSC 35079.

Figure 31. Dorsal valve, external mould including impression of ventral interarea; the bladelike posterior face of the cardinal process is impressed on the wedge of matrix that filled the space between the pseudodeltidium and the chilidium; GSC 35082.

Figure 32. Ventral valve, internal mould, GSC 35081.

Figures 33, 34. Ventral valve, external and internal moulds, GSC 35080.

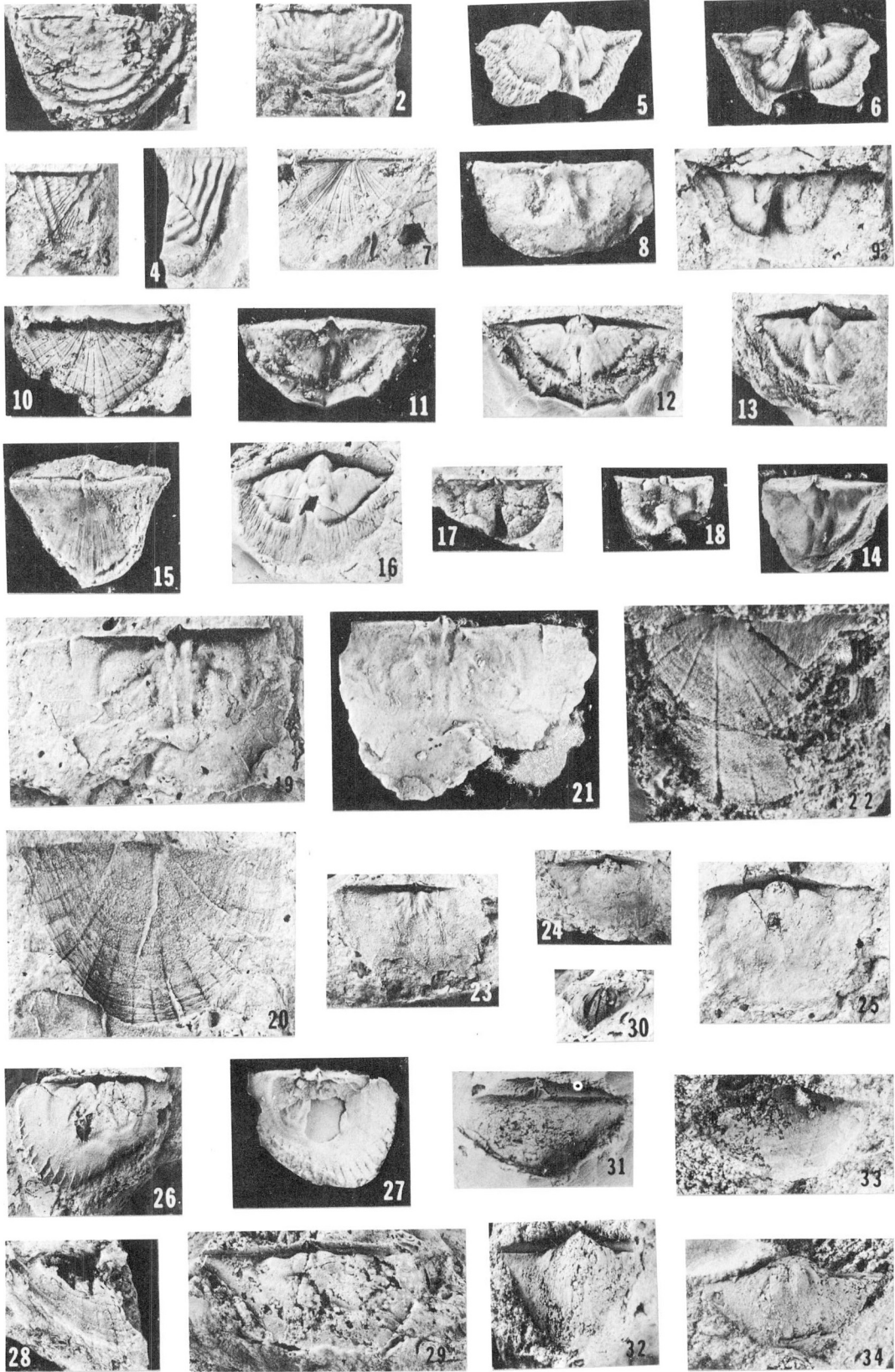




Plate 7

*Rugostrophia latireticulata* new species (all at  $\times 1.5$ )

Figures 1, 2. Dorsal valve, internal and external moulds, holotype, GSC 35085.

Figures 3, 4. Ventral valve, internal and external moulds, paratype, GSC 35087.

Figures 5, 6. Ventral valve, external mould and rubber replica, paratype, GSC 35088.

Figure 7. Dorsal valve, internal mould, paratype, GSC 35086.

Figure 8. Ventral valve, internal mould, paratype, GSC 35089.

Porambonitid genus and species undetermined (figs. 9, 10, 12 at  $\times 2$ , fig. 11 at  $\times 5$ ). Locality: New World Island, 1/2 mile northwest of Village Cove, roadside, north side of Cottle's Island–Summerford road

Figures 9–12. Dorsal valve, internal mould, rubber replica of posterior part of interior, part of external mould enlarged to show detail of impression of ornament, and complete external mould, GSC 35090.

*Rhysostrophia?* sp. (all at  $\times 3$ )

Figure 13. Ventral valve, internal mould, GSC 35093.

Figures 14, 15. Dorsal valve, posterior and dorsal views, GSC 35094.

*Taffia?* sp. (all at  $\times 1.5$ )

Figures 16, 17. Ventral valve, partial external mould and internal mould, GSC 35045.

Figures 18–20. Ventral valve, rubber replica of interior, partial external mould and internal mould, GSC 35044.

Figure 21. Dorsal valve, internal mould, GSC 35046.

*Camerella?* sp. (both at  $\times 3$ )

Figures 22, 23. Ventral valve, partial external mould and internal mould, GSC 35091.

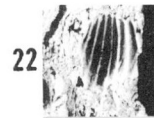
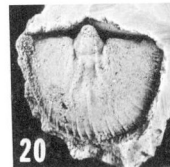
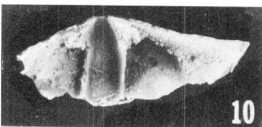
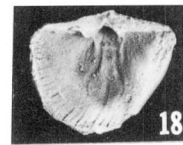
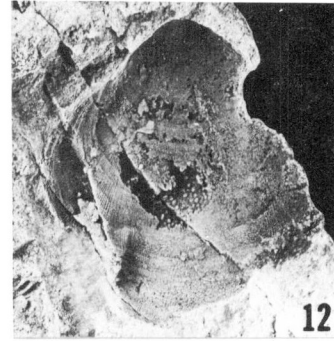
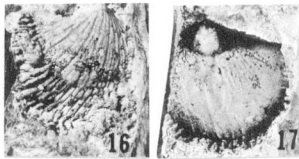
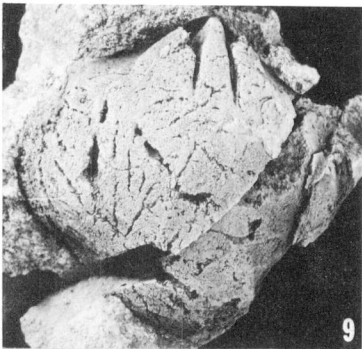
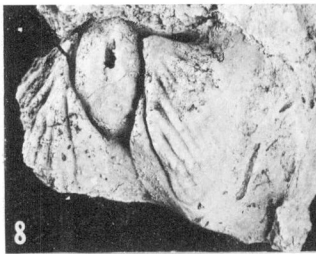
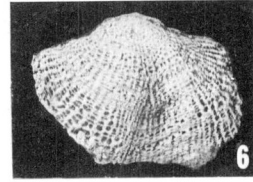
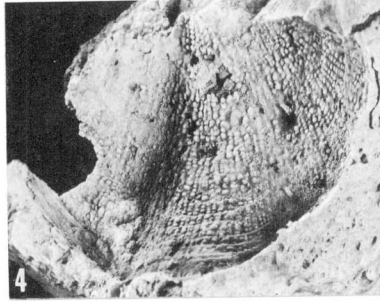
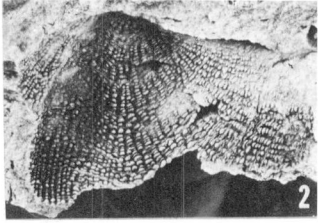
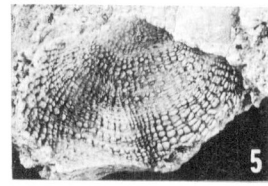
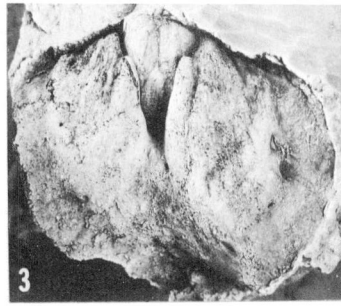
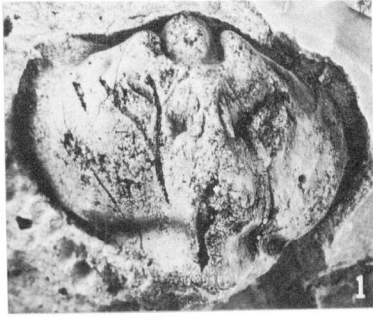


Plate 8

Thin sections tangential to shell surfaces at about midlengths  
of shells,  $\times 50$

*Ahtiella paucirugosa* new species

Figure 1. Note scattered elliptical areas, enlarged here to about 5 mm in diameter (i.e., 0.1 mm before enlargement), that are deflections of shell fibres around pseudopunctae; GSC 35057.

*Taffia?* sp.

Figure 2. The uninterrupted linear disposition of the shell fibres shows that the shell is not pseudopunctate; GSC 35049.

(Thin section prepared by W.C. Pinckney, Jr.; photographs by O.C. Karklins.)

