2009

Brachiopods from the Middle Devonian Hamilton Group of Southwestern Ontario, Canada

Junhui Wang
Western University

Brachiopods from the Middle Devonian Hamilton Group of Southwestern Ontario, Canada

(Spine Title: Hamilton Group Brachiopods of Ontario)

(Thesis Format: Monograph)

by

Junhui Wang

Graduate Program
in
Geology

A thesis submitted in partial fulfillment

of the requirements for the degree of

Doctor of Philosophy

School of Graduate and Postdoctoral Studies

The University of Western Ontario

London, Ontario, Canada

Abstract

The late Middle Devonian (Givetian) Hamilton Group of southwestern Ontario is well known worldwide for its diverse, abundant and well-preserved brachiopod fauna. Yet, despite their undoubted value as a paleontological resource, the Hamilton Group brachiopods have been largely ignored over the past few decades in terms of their systematics and potential biostratigraphic value.

A detailed systematic study of brachiopods collected from exposed strata of the Hamilton Group in the Arkona-Thedford-Ipperwash area of southwestern Ontario has led to the recognition of 50 species assigned to 34 genera, among which one species, *Devonochonetes arkonensis* n. sp., has been newly defined.

A quantitative study of 38 brachiopod associations from the Hamilton Group of southwestern Ontario and equivalent strata in the Appalachian and the Michigan basins, using Q-mode (taxa as variables) and R-mode (localities/ages as variables) cluster analyses, principal component analysis, and four faunal similarity analyses (i.e., Jaccard similarity, Dice similarity, Simpson's coefficient of similarity, and Raup-Crick similarity indices), has revealed that the late Middle Devonian (Givetian) brachiopod faunas from time-equivalent strata of the Michigan and Appalachian are distinct, allowing identification of two separate faunal subprovinces.

In spite of its present-day position in the southeastern part of the Michigan Basin, southwestern Ontario had brachiopod associations which were more similar to those in contemporaneous strata of the Appalachian Basin during the deposition of the lower and middle Hamilton sediments. This may have been related to the absence of a topographic high in the present-day Findlay Arch area that would have otherwise prevented immigration of Appalachian Basin fauna into the study area. During the deposition of the upper Hamilton strata, the southwestern Ontario brachiopod associations developed a closer affinity to those of the Michigan Basin, suggesting that the immigration of brachiopod faunas from the Appalachian Basin into the study area was impeded. This change in faunal affinity may have been related to the formation of a local arch at present-day Cleveland area of Ohio that blocked the immigration of Appalachian Basin taxa into the study area.

Keywords: brachiopods, Hamilton Group, Middle Devonian, southwestern Ontario, Arkona-Thedford-Ipperwash area, taxonomy, biogeographic investigations, brachiopod association, cluster analysis, principal component analysis.

Acknowledgements

First of all, I am greatly indebted to my principal supervisor, Dr. Cameron J. Tsujita, for suggesting the research topic and supervising my Ph.D. research. I am truly appreciative of his encouragement, generous assistance, helpful guidance, and endless patience throughout my course of Ph.D. studies at the University of Western Ontario.

I would also like to thank my co-supervisor, Dr. Jisuo Jin, for kindly giving me a lot of professional advice and assistance on my Ph.D. research, especially on brachiopod taxonomy.

I sincerely extend my gratitude to Dr. Alfred C. Lenz, also a member of my supervisory committee, for his insightful suggestions and constructive comments during all stages of my research.

I am grateful to a variety of people who provided assistance in different forms. I would especially like to thank Mr. Jay M. Hoeberechts, Mr. Michael Topor, Mr. John Topor, Mr. Don Demaray, and Mr. Bob O'Donnell for helping me in the field. I also sincerely thank Dr. Daniel Miller, the manager of the Museum of Paleontology at the University of Michigan, for his generous assistance in lending supplemental brachiopod samples for my research. Thanks are also extended to fellow grad students of the Department of Earth Sciences at Western who provided advice on the preparation of this thesis and other aspects of my studies. I would hate to forget listing any of my friends, so, I prefer to thank all of you at once.

Last, but by no means least, I am deeply grateful to my family and relatives. Without their undying emotional support, I am not sure that I could have been so mentally strong to complete my thesis abroad.

This project was funded by an NSERC Discovery Grant awarded to Dr. Cameron J. Tsujita.

Table of Contents

Chapter 1: Introduction

Chapter 2: Taxonomy and Biostratigraphy of Brachiopods from the Middle Devonian Hamilton Group of Southwestern Ontario

Chapter 3: Brachiopods from the Middle Devonian Hamilton Group of southwestern Ontario and equivalent strata in the Appalachian and

List of Tables

List of Figures

List of Plates

Chapter 1: Introduction

1.1 General Introduction

The Middle Devonian Hamilton Group is a regionally widespread succession of non-marine to offshore-marine sediments that extends over a large portion of central and eastern North America, including Virginia, Pennsylvania, Ontario, Ohio, New York, Missouri, Michigan, Maryland, Kentucky, Indiana, and Illinois (Cooper, 1930a). Contained in this succession are the first coarse clastic sediments that were shed westward from the rising Acadian highlands in Eastern North America into the subsiding Appalachian Foreland Basin (Slattery, 1995).

As noted by Bartholomew (2006), research on the Middle Devonian Hamilton Group of eastern North America has focused on exposures in two main areas: 1) the Appalachian Basin in New York, Ontario, Pennsylvania, and eastern Ohio, 2) the Michigan Basin in Michigan, Wisconsin, and western Ohio. The Hamilton Group as a whole spans latest Eifelian through middle Givetian time, representing approximately 6-7 million years of depositional history (Harland et al., 1982).

1.1.1 Tectonic Setting

In southwestern Ontario, strata of the Middle Devonian Hamilton Group, are more or less restricted to a saddle-like structural low named the Chatham Sag separating the Algonquin and Findlay arches (Landing and Brett, 1987). Here, the Hamilton Group of southwestern Ontario effectively lies on the eastern edge of the Michigan Basin and to the west of the Appalachian Foreland Basin, which is separated from the Michigan

Basin by the Algonquin Arch (Figure 1-1).

1.1.1.1 The Michigan Basin

The Michigan Basin is a saucer-shaped intracratonic basin within which sediment was deposited over an interval of more than 200 Ma and accumulated to a maximum thickness of 4000-5000 m at its centre; Its diameter is about 400-500 km and covers a total area between 198,387-207,000 km^2 (Fisher et al., 1988; Catacosinos et al., 1990; Howell and van der Pluijm, 1990, 1999; Klein, 1991). The Michigan Basin, which contains predominantly carbonate rocks (limestones and dolostones) (Howell and van der Pluijm, 1999), underlies a significant portion of southwestern Ontario, Ohio, northeastern Illinois, eastern Wisconsin, northern Indiana, and most of Michigan (Fisher et al., 1984; Catacosinos et al., 1990).

The development of the Michigan Basin appears to have been complex and three main hypotheses have been proposed to explain why and how it may have formed. The first hypothesis attributes basin development to thermal contraction, based on the existence of a gravity anomaly in the upper crust directly underlying the basin. The origin of this anomaly is thought to have been linked to the incursion of dense mantle material into the crust; more specifically it is envisaged that the added mass of upwelled mantle rocks loaded the lithosphere sufficiently to have caused it to flex and subside in response (Quinlan, 1987; Howell and van der Pluijm, 1999).

The second hypothesis on the development of the Michigan Basin, as proposed by Ahern and Dikeou (1989), is that a single heating anomaly in the Cambrian (approximately 500 Ma) promoted the alteration of greenschist to amphibolite in basement rocks of the Michigan region. The authors attribute the initial phase of subsidence recorded in the Michigan Basin to the crustal downwarping that resulted from this metamorphic event, and cite subsequent thermal contraction as the cause of second phase of basinal subsidence that occurred in the Middle Ordovician.

In the third hypothesis, presented by Howell and van der Pluijm (1990, 1999), the origin and development of the Michigan Basin is interpreted to have involved a stress-induced, crustal-weakening mechanism. Using well-log correlations and estimates of paleobathymetry, the authors recognized multiple major phases of basin evolution, each characterized by one of four different styles of subsidence in the basin (referred to as trough-shaped, bowl-shaped basin-centred, saucer-shaped basin-centred, and regional tilting).

Howell and van der Pluijm (1999) interpreted that the Michigan Basin was characterized by "trough-shaped" subsidence from the Late Cambrian to the Early Ordovician, followed by bowl-shaped basin-centered (narrow basin) subsidence from Early to Middle Ordovician time, and regional tilting toward the east from mid- to Late Ordovician time. Interpreted to have followed this regional tilting was a phase of saucer-shaped basin-centred (broad basin) subsidence during Silurian time and, still later, reverted back to another phase of bowl-shaped basin-centered (narrow basin) subsidence during the latest Silurian and Middle Devonian time; The following is another phase of saucer-shaped basin-centered (broad basin) subsidence during the deposition time of the Middle Devonian Traverse Group sediments. Regional (eastward) tilting was interpreted to have resumed during the Upper Devonian and continued into the later Paleozoic, but due to erosion of strata and uncertainties in the

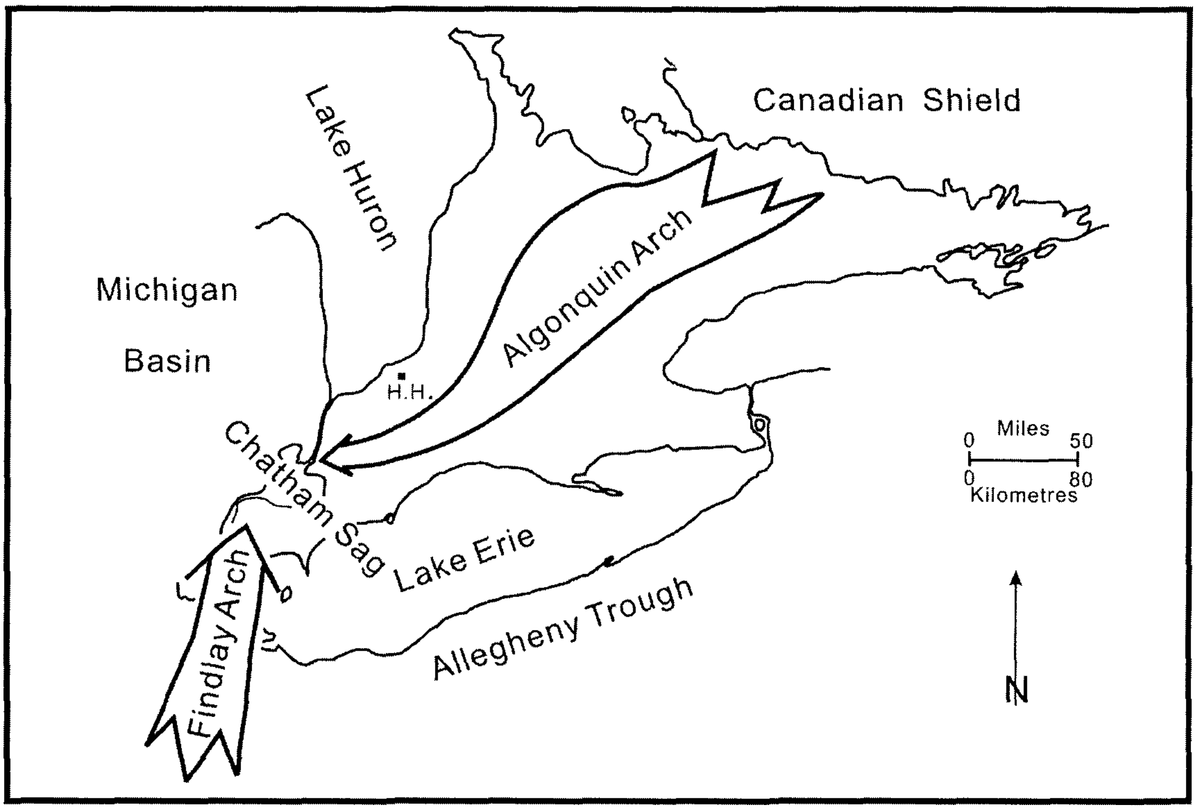


Fig. 1-1. The structural setting of southwestern Ontario. H. H., Hungry Hollow, Arkona, West Williams Township, Middlesex County, southwestern Ontario (After Winder and Sanford, 1972).

paleobathymetric calculations, evidence of this latter episode of tilting was deemed questionable (Howell and van der Pluijm, 1999).

In addition to the above-described subsidence patterns, Howell and van der Pluijm (1999) recognized two distinct styles of erosion (basin-wide and marginal) recorded by unconformities, noting the absence of significant basin-centered unconformities would be expected if basin subsidence was controlled solely by thermal mechanisms. They concluded that the episodic bowl-shaped basin-centered subsidence could be accounted for by a stress-induced, crustal-weakening mechanism, whereas saucer-shaped basin-centered subsidence could be best attributed to thermal contraction that followed lower crustal attenuation associated with the narrow-subsidence episodes.

1.1.1.2 The Appalachian Basin

The Appalachian Basin is a peripheral foreland basin located on the inboard (cratonward) side of an intercontinental collision zone. It is interpreted to be a multistage basin that developed via lithospheric downwarp under the loads of successive Taconic (Ordovician-Silurian), Acadian (Devonian-Mississippian), and Alleghanian (late Palaeozoic) overthrusts in the adjacent Appalachian Mountains (Quinlan and Beaumont, 1984; Castle, 2001a). Corresponding to the foreland peripheral bulge that formed via flexural uplift of the continental crust are the north-north-east to south-south-west-trending Algonquin, Findlay and Cincinnati arches on the western margin of the basin (Castle, 2001a).

In its initial stage of development (during the Taconic Orogeny), the Appalachian Basin was underfilled with sediment, owing to the accommodation produced by flexural loading and eustasy having exceeded the rate of sediment influx. Consistent with Sinclair's (1997) claim that marine facies of underfilled basins represent deposition in water depths that can exceed 200 m, black shale, recording deposition in deep, oxygen-deficient waters, was the predominant siliciclastic facies deposited in the Appalachian Basin at that time (Hay and Cisne, 1988; Ryder et al., 1998). Thick clastic sediment wedges, built from the detritus shed from the Taconic mountains, encroached westward into the Appalachian Basin during the later stages of the Taconic Orogeny, leading to the predominance of shallow marine facies in the basin by latest Devonian time (Rodgers, 1967, 1970; Johnson, 1971).

The Acadian Orogeny was the most significant tectonic event that affected eastern North America during the Devonian. An orogenic belt from maritime Canada to the Southern Appalachians of Alabama and Georgia was formed via the collision of the eastern margin of Laurentia with the Avalon terrane (Ver Straeten, 2004). The Acadian Orogeny is thought to have involved at least four large-scale cycles of tectonism and quiescence during the range of the beginning of the Early Devonian to the Early Mississippian (Ettensohn, 1985a; Bradley and Hanson, 1989). On the assumption that Avalon was indeed a single landmass, the multiple tectonic cycles probably recorded the oblique convergence and collision of the Avalonian microcontinent with separate promontories on the eastern Laurentian margin (Thomas, 1977).

Ettensohn (1985a) discussed the first three Acadian tectophases and indicated the last tectophase ended in the earliest Mississippian. According to Ettensohn (1985a), the first Acadian tectophase commenced in the northern Appalachians due to collision between the Avalon terrane and the St. Lawrence promontory (Figure 1-2). This collision occurred either during the late Emsian (Boucot et al., 1964a) or during the late Pragian to early Emsian (Donohoe and Pajari, 1973). The second tectophase spanned the late Eifelian through Givetian and culminated in the collision of the Avalon terrane with the New York promontory during the Middle-Late Devonian transition; this tectophase is represented in the rocks of the Hamilton Group and Tully Limestone. The Catskill Delta complex which formed from the siliciclastic sediments that were shed into the Appalachian Basin from the rising Acadian highlands in the east is best developed in south-central New York and adjacent portions of Pennsylvania (Ettensohn, 1985a). The third tectophase, which spanned the Frasnnian to earliest Tournaisian, represents the southward migration of deformation and collision with the Virginia promontory during the Devonian-Mississippian transition (Ettensohn, 1985a).

The Alleghanian Orogeny, which was the final phase of the Late Paleozoic construction of the supercontinent Pangea, culminated with the continent-continent oblique collision between Laurentia and Gondwana (Becker et al., 2005). Thomas (1977) stated that it was during the Alleghanian Orogeny that two Late Paleozoic clastic wedges (the Mauch Chunk-Pottsville in the central Appalachian and the Pennington-Lee in the southern Appalachian) in the Appalachian Basin developed. Deposition of late Mississippian siltstones and mudstones marked the end of carbonate sediment and coarse-grained, quartz-rich, cratonward-prograding, fluvial deposits further marked the initiation of continent-continent collision and cratonward advancement of the tectonic load during the Pennsylvanian (Becker et al., 2005).

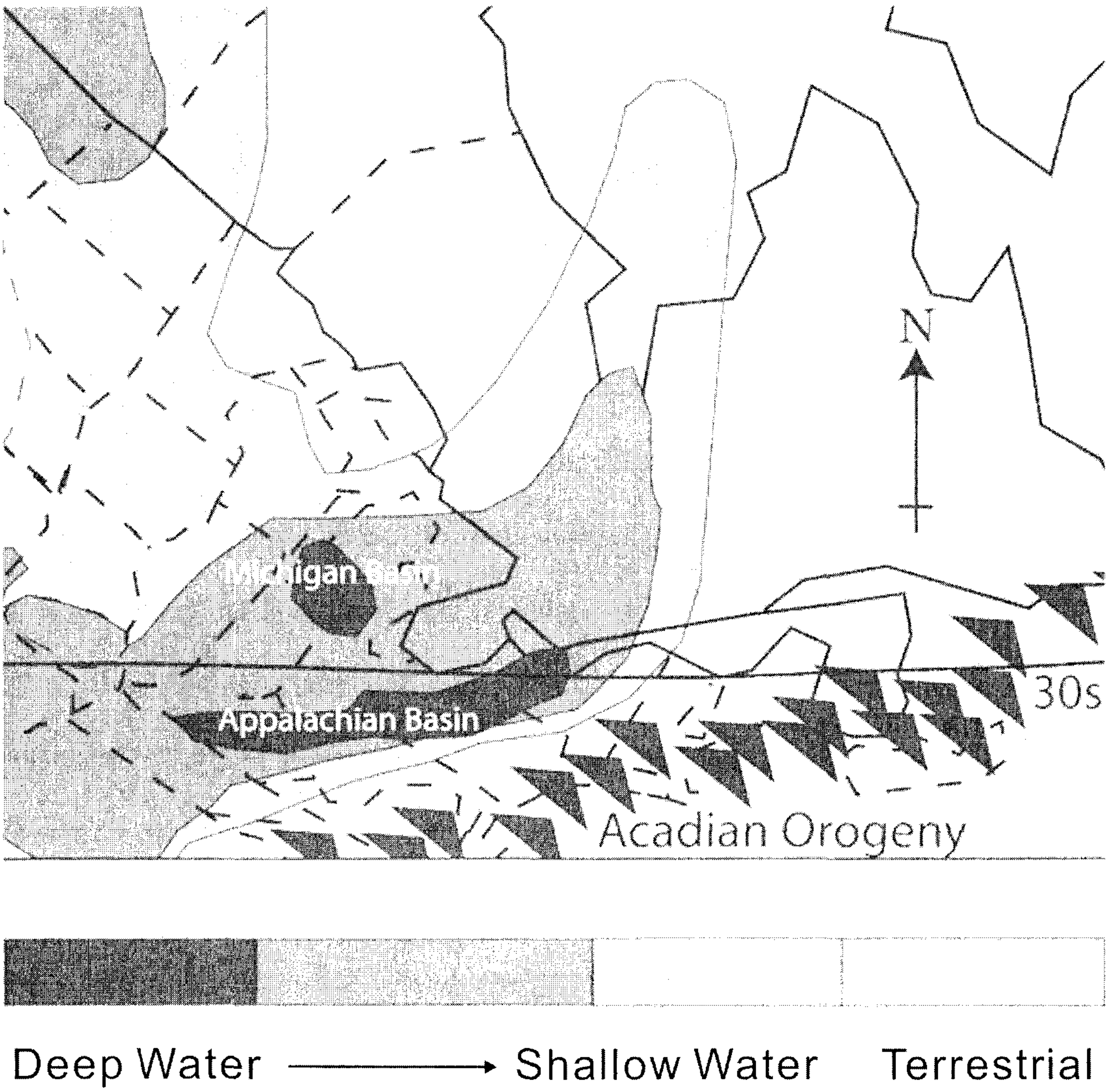


Fig. 1-2. Paleogeographic map of the Middle Devonian eastern North America showing the location of the Appalachian Basin and the orientation of the Avalon Terrane which was colliding with the southeastern craton of Laurentia (After Bartholomew et al., 2006).

1.1.2 The Hamilton Group in the Appalachian Basin of New York State

The Hamilton Group in the Appalachian Basin of New York State is an eastward-thickening wedge of mainly siliciclastic sediments, which are entirely marine, except those in the easternmost part where non-marine facies have been reported (Brett et al., 1991). Cooper (1930a, 1930b, 1933, 1934) divided the Hamilton Group into four formations. In ascending order, these are the Marcellus, Skaneateles, Ludlowville, and Moscow formations. In central New York, the Marcellus Formation is a 55 m thick siliciclastic unit mainly composed of dark shales and siltstones. In central New York, from Skaneateles Lake to the Unadilla Valley, the Skaneateles Formation shows a transition from basinal shales to a sandy shallow shelf and the thickness varies from less than 20 m at Lake Erie to 140 m in the Chenango Valley. The Ludlowville Formation consists of 80 m thick fossiliferous mudstone, siltstone and sandstone in central New York. In western New York, the Ludlowville Formation is a 65 m thick sequence of shaley carbonate. And finally, in western New York, the Moscow Formation is comprised of grey, calcareous shales, mudstones, and thin limestones. Rickard (1975) divided these four formations into members, as illustrated in Table 1-1.

1.1.3 The Hamilton Group in the Michigan Basin of Michigan State

The Hamilton-equivalent strata in the Michigan Basin of Michigan State belong to the Traverse Group, a marine succession that ranges from 25 m to 165 m in thickness (Ehlers & Kesling, 1970; Wylie & Huntoon, 2003). The general stratigraphy of this group in Michigan State is depicted in Table 1-2. The Traverse Group records deposition in a diverse suite of environments, including shallow water carbonate lagoons, coral-stromatoporoid reefs, storm dominated mixed carbonate-siliciclastic shelf, and deeper, offshore, muddy shelf (Ehlers and Kesling, 1970). Accordingly, the predominant lithologies are limestone, argillaceous limestone, and shale. Outcrops of this succession occur at the northern portion of the Michigan Basin (Imbrie, 1959).

According to Wylie and Huntoon (2003), several unconformities exist in the Traverse Group. The Rockport Quarry Limestone unconformably overlies the Bell Shale. The Newton Creek Limestone, recording deposition in open-marine and lagoonal environments, is unconformably overlain by the Alpena Limestone. The Four Mile Dam Formation also unconformably overlies the Dock Street Clay Member, and the Norway Point Formation unconformably underlies the Potter Farm Formation. The same authors regard that, the Squaw Bay Limestone, which unconformably overlies the Thunder Bay Limestone, as the uppermost formation of the Traverse Group. It has been argued, however, that the Squaw Bay Limestone is of Late Devonian age and should be separated from the Middle Devonian Traverse Group (Budai, et al., 2002); indeed a study of Devonian conodonts in the Michigan Basin by Orr (1971) has confirmed that the Squaw Bay Limestone should be assigned to the Upper Devonian.

1.1.4 The Hamilton Group of southwestern Ontario

The Ontario succession of the Hamilton Group is significant in that it provides a stratigraphic bridge between the thicker coeval successions in the Appalachian and the Michigan basins and may aid in interbasinal correlation (Figure 1-3). During the Acadian Orogeny, large volumes of siliciclastic detritus eroded from the Acadian

Group	Formation	Member	Main Lithology
Hamilton	Moscow	Windom	Shale
		Portland Point	Limestone
	Ludlowville	Owasco	Shale
		Spafford	Shale
		Ivy Point	Sandstone
		Otisco	Shale
		Centerfield	Limestone
	Skaneateles	Butternut	Shale
		Pompey	Shale
		Delphi Station	Shale
		Mottville	Limestone
	Marcellus	Cardiff	Shale
		Chittenango	Shale
		Cherry Valley	Limestone
		Union Springs	Shale

Table 1-1. The stratigraphy of the Hamilton Group in central New York (After Rickard, 1975).

Group	Formation/Member		Main Lithology
Traverse	Thunder Bay Formation		Shale
	Potter Farm Formation		Argillaceous limestone
	Norway Point Formation		Claystone
	Four Mile Dam Formation		biohermal limestone
	Alpena Limestone	Dock Street Clay Mbr.	Claystone
		Lower Alpena Limestone	Limestone
	Newton Creek Limestone		Limestone
	Genshaw Fm.	Upper Genshaw Fm.	Grey limestone
		Killians Mbr.	Siliceous shale
		Lower Genshaw Fm.	Grey limestone
	Ferron Point Formation		Calcareous shale
	Rockport Quarry Limestone		Biohermal and lithographic limestone
	Bell Shale Formation		Shale

Table 1-2. The stratigraphy of the Traverse Group in Michigan state (After Budai et al., 2002; Ehlers and Kesling, 1970; Orr, 1971; Tyler, 1969; Wylie and Huntoon, 2003).

highlands were shed westward into the Appalachian Foreland Basin. Deposition of coarse-grained siliciclastic sediments (e.g., gravels and sands) tended to be restricted to proximal, non-marine to marginal-marine environments on the eastern side of the Appalachian Basin, whereas siliciclastic mud dominated the marine deposits of the central and western sectors of the Appalachian Basin (Ettensohn, 1985b). The Ontario succession of the Hamilton Group marks a time when the Appalachian Basin had become overfilled with sediment and thus allowed the apron of siliciclastic mud to encroach into the Michigan Basin (Brett and Baird, 1996). The detailed stratigraphy setting and paleontological background of the Hamilton Group of southwestern Ontario will be described in the following sections.

1.2 Stratigraphic Setting

Alexander Murray (1845, 1850, 1852) was the first to describe the Devonian geology specifically of southwestern Ontario. He divided Devonian strata into the following units (in ascending order): Oriskany Sandstone, Corniferous Limestones, and the Hamilton, Portage, and Chemung groups.

Logan (1863) followed Murray's classification, adding detailed stratigraphic descriptions and assigning the ages of each stratigraphic unit (Uyeno, et al., 1982); the exposures studied by him included the well-known exposures of the Hamilton Group in the Arkona-Thedford area. Logan's stratigraphic work was followed by that of such authors as Shimer and Grabau (1902), Stauffer (1915), Cooper and Warthin (1942) and Stumm et al. (1956). Later studies were focused on the correlation of Hamilton Group

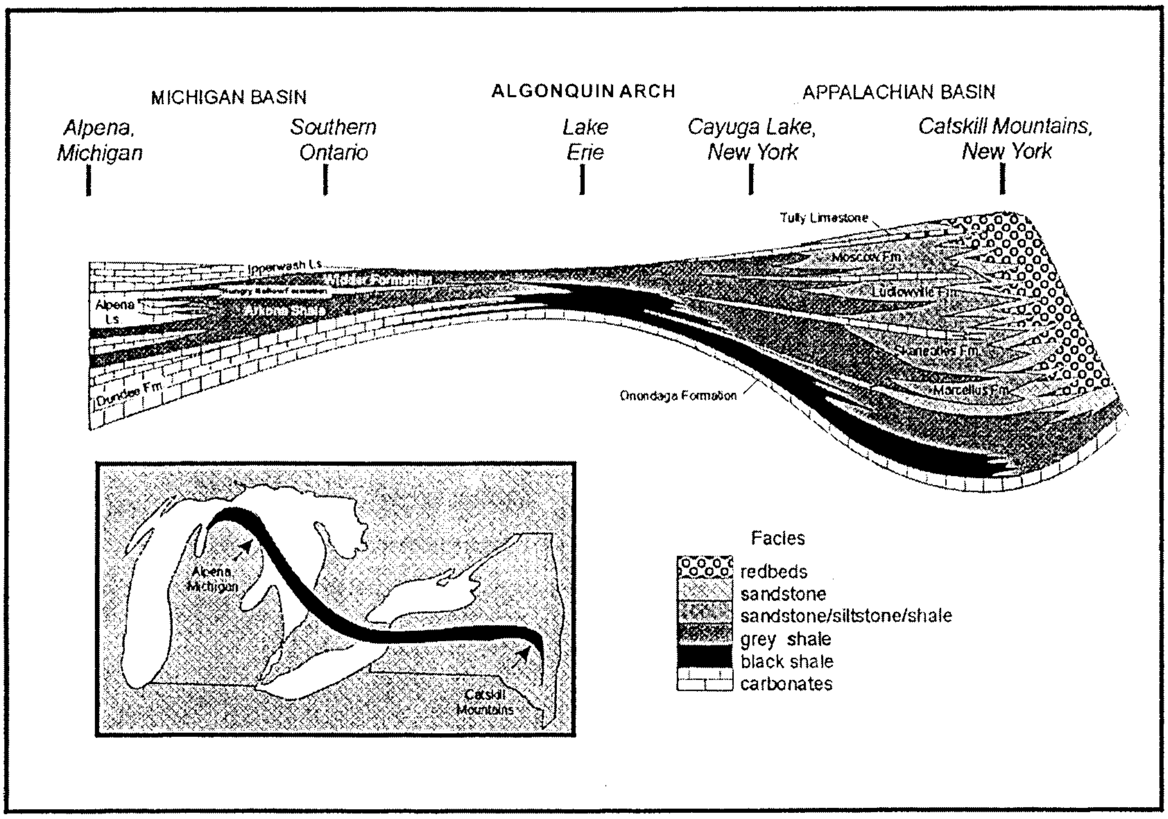


Fig. 1-3. Middle Devonian Hamilton Group successions of southwestern Ontario with respect to basin and arch features (After Dunbar, 1960).

strata in Ontario with those in New York (Appalachian Basin) and Michigan and northwestern Ohio (Michigan Basin), such as those of Mitchell (1967) and Rickard (1984). More recently, stratigraphic and paleontological overviews of the Hamilton Group of Ontario were written by Uyeno et al. (1982) and Tsujita et al. (2001).

In southwestern Ontario, the Hamilton Group is composed of thick intervals of predominantly terrigenous mudstones, argillaceous carbonates, and thinner intervening units of bioclastic carbonates. The Middle Devonian (Givetian) Hamilton Group in southwestern Ontario has conventionally been divided into six formations. These are, in ascending order, the Bell Formation, Rockport Quarry Formation, Arkona Shale, Hungry Hollow Formation, Widder Formation, and Ipperwash Formation (Uyeno et al., 1982). The lower part of the group, including the entire Bell Shale and Rockport Quarry Formation as well as the lower half part of the Arkona Shale, is known only in the subsurface (Uyeno et al., 1982).

The Bell Formation consists of soft blue-grey calcareous shale with limestone lenses and OGS (Ontario Geological Survey) drill cores show that this basal formation is a homogeneous unit, rich in shelly debris. This unit has a maximum thickness of 20 m in northeastern Michigan, becoming thinner in a southeastward direction; it is only approximately 10 m thick in the northern portion of Kent County in Ontario (Sanford, 1967; Johnson et al., 1985; Tsujita et al., 2001).

The Rockport Quarry Formation is very fossiliferous, and consists of grey and brown, fine-grained, argillaceous limestone with occasional shale layers that increase in number and thickness to the southeast. The average thickness of the formation is about 20 m in the northern portion of the Michigan Basin, but only 6 m thick in southwestern

Ontario (Sanford, 1967; Tsujita et al., 2001).

The Arkona Shale consists of poorly to moderately fossiliferous blue-grey calcareous shales; minor thin beds of argillaceous limestone are present in the lower part (Tsujita et al., 2001). The contact with the underlying Rockport Quarry Formation is not exposed; however, the uppermost part of the unit is well exposed at Hungry Hollow, Rock Glen, Tile Yard at Thedford, and numerous bank exposures along the Ausable River near the villages of Arkona and Thedford, about 50 km west of London (Telford and Johnson, 1984; Tsujita et al., 2001). A study of OGS drill cores has revealed this unit to have an average thickness of about 20 m, and a maximum thickness of 37 m in southwestern Ontario (Sanford, 1967; Tsujita et al., 2001).

In the exposed upper part of the Arkona Shale Formation as defined in previous work before Bartholomew et al. (2006), fossil pavements of *Mucrospirifer-Devonochonetes*-dominated brachiopod fauna are quite common (Pl. 1-1, fig. 4; Pl. 1-2, fig. 5). Besides these two dominant brachiopod species, *Mucrospirifer mucronatus* (Conrad, 1841) and *Devonochonetes arkonensis* n. sp., other brachiopod species collected from these strata include: *Strophodonta* (*Strophodonta*) *demissa* (Conrad, 1842), *S. extenuata ferronensis* Imbrie, 1955, *S.* cf. *fascis* Imbrie, 1959, *Devonochonetes coronatus* (Conrad, 1842), *Productella truncata* (Hall, 1857), *Devonalosia wrightorum* Muir-Wood & Cooper, 1960, *Floweria arctostriata* (Hall, 1843), *Spinocyrtia mourantae* Ehlers& Wright, 1955, *Cyrtina arkonensis* Ehlers & Wright, 1975.

The sharp contact between the Arkona Shale and the overlying Hungry Hollow Formation defined in previous work before Bartholomew et al. (2006) is marked by the presence of numerous *Cruziana* and *Rusophycus* burrows at the base of the Tile Yard Bed (Pl. 1-5, fig. 3), which was considered as the lowermost bed of the Hungry Hollow Formation (Bartholomew et al., 2006). The burrowing occurred in at least three distinct phases: the first-generation traces, identified as *Cruziana reticulata,* which are about 1-2 cm in diameter; the second-generation, large-sized (>10 cm in diameter) traces are assigned to the ichnospecies *Rusophycus bilobatum* and *Cruziana transversa.* The third-generation traces are dominated by *Planolites beverleyensis* which penetrate the above mentioned traces (Tsujita et al., 2001).

The Hungry Hollow Formation is a relatively thin unit, about 1.50- 1.75 m in thickness as defined in the previous work before Bartholomew et al. (2006). Mitchell (1967) divided this formation into nine units based on lithologic characteristics. Mitchell's lower units 1-3, crop out as a single weathering-resistant limestone ledge, which he divided into a 3 inch-thick lower limestone unit, a 2 inch-thick middle shale unit, and 1/4-1/2 inch-thick upper bioclastic limestone unit. However, these three separate lithologies are not distinct in some outcrops due either to nondeposition or more likely to a consistent short-term depositional environment (Kralik, 1992) (Pl. 1-1, fig. 3; Pl. 1-3, fig. 2). Landing and Brett (1987) recognized only two distinct divisions in the weathering-resistant limestone ledge: the lowest unit is a 3-6 cm thick brownish-grey, medium to coarse grained, hummocky cross-bedded wackestone to packstone with some small pyrite nodules and phosphatic clasts; the upper unit of this ledge is a 7.34-10.97 cm thick grey, fine-medium grained wackestone to packstone with rich fossil debris.

Donato (2003) followed Mitchell's stratigraphic division of the Hungry Hollow

Formation and described that unit 4 consists of 4-6 cm thick, grey, calcareous shale and unit 5 is a 3-6 cm thick, finely laminated, dark-grey to black shale (Pl. 1-1, fig. 3; Pl. 1-3, fig. 3). Brachiopod species in unit 4 are mainly *Mucrospirifer mucronatus* (Conrad, 1841), *Athyris spiriferoides* (Eaton, 1832), *Athyris vittata* Hall, 1860, *Ambocoelia tuberculata* Goldman & Mitchell, 1990, and *Leiorhynchus kelloggi* Hall, 1867. In unit 5, abundant crushed *Leiorhynchus kelloggi* and their moulds are present (Pl. 1-1, fig. 5; Pl. 1-3, fig. 4).

Units 6-8 formerly belonged to one unit called the Encrinal Limestone/Unit (Shimer and Grabau, 1902; Cooper and Warthin, 1941; Donato, 2003) (Pl. 1-1, fig. 3; Pl. 1-2, fig. 2; Pl. 1-4, fig. 1). Unit 6 consists of 12-15 cm thick brownish-grey, crinoidal packstone to grainstone with brachiopod species *Protoleptostrophia perplana* (Conrad, 1842), *Rhipidomella vanuxemi* (Hall, 1857), *Rhipidomella penelope* (Hall, 1860), *Camarotoechia thedfordensis* Whiteaves, 1898, *Athyris spiriferoides* (Eaton, 1832), *Athyris vittata* Hall, 1860, *Nucleospira concinna* (Hall, 1843), *Ambocoelia tuberculata* Goldman & Mitchell, 1990, *Mucrospirifer mucronatus* (Conrad, 1841), and *Cranaena romingeri* (Hall, 1863); abundant trilobite burrows present at the basal part of unit 6, although the burrows are not preserved as well as those at the bottom surface of unit 1; Unit 7 is present at some outcrops as a 1-3 cm thick recessive-weathering, argillaceous limestone containing some corals; Unit 8 consists of 30-40 cm thick, brownish-grey, echinoderm grainstone containing a 2-4 cm thick "encrusted hard ground" cap (Donato, 2003). Some brachiopod species are present in units 7-8. They are as follows: *Protoleptostrophia perplana*, *Megastrophia concava* (Hall, 1857), *Pholidostrophia nacrea* (Hall, 1857), *Rhipidomella vanuxemi*, *Rhipidomella penelope*, *Camarotoechia* *thedfordensis*, *Atrypa* (*Atrypa*) *reticularis* (Linnaeus, 1758), *Athyris spiriferoides*, *Athyris vittata*, *Spinocyrtia granulosa* (Conrad, 1839), *Ambocoelia tuberculata*, *Mucrospirifer mucronatus*, and *Cranaena romingeri*.

Unit 9 was formerly termed the coral unit/biostrome, consisting of approximately 1 m thick calcareous shales with abundant corals and diverse brachiopods (Pl. 1-1, fig. 2; Pl. 1-2, fig. 2; Pl. 1-3, fig. 5; Pl. 1-4, fig. 1; Pl. 1-5, fig. 2; Pl. 1-8, fig. 3); approximately 10 cm thick, poorly consolidated, laterally consistent, echinoderm packstone is present in the lower one third of unit 9 (Donato, 2003). Inarticulate brachiopods identified from this unit include: *Lingula*? *thedfordensis* Whiteaves, 1889, *Orbiculoidea doria* (Hall, 1863), *Petrocrania hamiltoniae* (Hall, 1860), *Philhedra crenistriata* (Hall, 1860). Articulate brachiopods identified from this unit include: *Douvillina* cf. *inaequistriata* (Conrad, 1842), *Protoleptostrophia perplana*, *Strophodonta* (*Strophodonta*) *demissa* (Conrad), *Strophodonta demissa*, *Strophodonta* sp., *Strophodonta titan titan* Imbrie, 1959 ?, *Megastrophia concava*, *Pholidostrophia nacrea*, *Devonochonetes coronatus*, *Floweria* sp., *Rhipidomella vanuxemi*, *Rhipidomella penelope*, *Pentamerella* cf. *pavilionensis* (Hall, 1860), *Callipleura nobilis* (Hall, 1860), *Camarotoechia thedfordensis*, *Leiorhynchus laura* (Billings, 1860), *Stenoscisma kernahani* (Whiteaves, 1898), *Atrypa* (*Atrypa*) *reticularis*, *Pseudoatrypa* cf. *devoniana* (Webster, 1921), *Athyris spiriferoides*, *Athyris vittata*, *Charionella scitula* (Hall, 1843), *Pentagonia bisulcata* (Cooper) ?, *Nucleospira concinna*, *Parazyga* cf. *hirsuta* (Hall, 1857), *Spinocyrtia granulosa*, ? *Mediospirifer* sp., *Ambocoelia tuberculata*, *Mucrospirifer mucronatus*, *Elita fimbriata* (Conrad, 1842), *Cyrtina coultisorum* Ehlers & Wright, 1975, *Cranaena romingeri*, *Cranaena harmonia* (Hall, 1867), and *Cryptonella* *attenuata* (Whiteaves, 1898).

The contact between the Widder Formation and the underlying Coral Unit of the Hungry Hollow Formation defined in previous work before Bartholomew et al. (2006) appears to be gradational in terms of lithology; however, the boundary can be identified by the absence of corals in the basal approximately 0.23 m thick calcareous shale beds of the Widder Formation (Pl. 1-3, figs. 5-6).

The Widder Formation is a succession of soft, grey, calcareous shale with interbeds of blue-grey, fine-grained, argillaceous limestone and coarse-grained, crinoidal bioclastic limestone, and as well as horizons of nodular limestone (Uyeno et al., 1982; Tsujita et al., 2001). Based on lithology, Wright and Wright (1961) divided the approximately 13.8 m thick succession of the Widder Formation in the glen at the so-called "No. 4 Hill" within the study area into 23 Units (Pl. 1-4, figs. 2-4). Unit 1 through Unit 14 comprises approximately 10.0 m thick grey calcareous shale with brachiopod species *Protoleptostrophia perplana*, *Pholidostrophia nacrea*, *Devonochonetes arkonensis* n. sp., *Leiorhynchus laura*, *Athyris vittata*, *Athyris spiriferoides*, *Ambocoelia tuberculata*, *Cyrtina angularis*, and more abundant *Mucrospirifer mucronatus*; the combined thickness of Unit 15 through Unit 22 is approximately 3.8 m and comprises crinoidal packstone/grainstone beds (each approximately 0.15 – 0.50 m thick) and alternating thinner beds of soft, calcareous shales (Bartholomew et al., 2006) with brachiopod species *Protoleptostrophia perplana*, *Strophodonta demissa*, *Megastrophia concava*, *Pholidostrophia nacrea*, *Devonochonetes arkonensis* n. sp., *Floweria arctostriata*, *Leiorhynchus laura*, *Athyris spiriferoides*, *Athyris vittata*, *Cyrtina angularis*, and abundant *Mucrospirifer* *mucronatus*. Unit 23 is approximately 0.71 m of grey to grey–buff calcareous shale with *Mucrospirifer mucronatus* (Wright and Wright, 1961).

Neither the contact between the Widder Formation and the overlying Ipperwash Formation nor the entire Ipperwash Formation are exposed in southwestern Ontario (Tsujita et al., 2001). Wright and Wright (1963) described the exposed ~ 2.08 m thick interval of rocks at Stony Point along the southern shore of Lake Huron, as "the Lower Ipperwash Limestone", and the exposed ~ 0.82 m thick interval of rocks near Kettle Point, as "the Upper Ipperwash Limestone".

In "the Lower Ipperwash Limestone" (Pl. 1-6, fig. 1), the following brachiopod species are present: *Protoleptostrophia perplana*, *Megastrophia concava*, *Rhipidomella penelope*, *Atrypa* (*Atrypa*) *reticularis*, *Spinocyrtia ravenswoodensis* Ehlers & Wright, 1955, *Spinocyrtia granulosa*, *Cyrtina staufferi*, and *Mucrospirifer mucronatus*. In "the Upper Ipperwash Limestone" (Pl. 1-7, fig. 1), the brachiopod species include:: *Protoleptostrophia perplana*, *Strophodonta demissa*, *Megastrophia concava*, *Rhipidomella vanuxemi*, *Rhipidomella penelope*, *Atrypa* (*Atrypa*) *reticularis*, *Pseudoatrypa* cf. *devoniana*, *Athyris spiriferoides*, *Athyris vittata*, *Spinocyrtia ravenswoodensis*, *Spinocyrtia granulosa*, *Cyrtina staufferi*, and *Mucrospirifer mucronatus*.

Recent changes have been made by Bartholomew et al. (2006) to the division of Hamilton Group strata as a result of a re-examination of the stratigraphic succession from a sequence stratigraphic perspective. The Bell Shale has been redefined to include the limestone beds previously included in the Dundee Formation. The former Rockport Quarry Formation becomes the basal part of the Arkona Shale Formation. The former

Hungry Hollow Formation is given member-scale status and becomes a basal member of the Widder Formation. The thickness of the Hungry Hollow Member is 1.30-1.55 m thick, since Units 1-5 in the previous work have been assigned to the underlying Arkona Shale.

According to the data from drill cores, the Golden Creek submember of the Petrolia Member (Widder Formation), which is exposed in patches along Golden Creek (Wright and Wright, 1961), near Thedford, Ontario, is ~ 4 m thick and comprised of shales and argillaceous, nodular and cherty limestones. The present brachiopod species in the Golden Creek submember are as follows: *Devonochonetes arkonensis* n. sp., *Atrypa* (*Atrypa*) *reticularis*, *Athyris spiriferoides*, *Spinocyrtia parvigranulata* Ehlers & Wright, 1955, *Cyrtina angularis*, and abundant *Mucrospirifer mucronatus*.

The overlying Stony Point submember, Petrolia Member (Widder Formation), which is exposed at Stony Point along the shore of Lake Huron and is equivalent to "the Lower Ipperwash Limestone" of Wright and Wright (1963), is ~ 1.5 m thick and is composed of crinoidal, glauconitic limestones whereas the upper Petrolia submember, which can only be observed in the subsurface, is 2-3 m thick and consists of soft, bluish grey shales and thin beds of limestone (Bartholomew et al., 2006). The Ipperwash Limestone (unnamed formation), as defined by Bartholomew et al. (2006), is equivalent to the former "Upper Ipperwash Limestone" of Wright and Wright (1963) and consists of 0.6-1 m dark-grey limestone, capped by a few centimetres of calcisiltite and black to bluish-purple chert.

The beds above the Ipperwash Member in Ontario are only preserved in the subsurface near Sania, Ontario. Bartholomew et al. (2006) studied a core from the subsurface near Sarnia and observed ~ 6 m of calcareous, fossiliferous grey shale which overlies the same chert bed at the top of the Ipperwash Member observed at Kettle Point. A pyritic discontinuity exists at the top of this 6 m unit and is overlain by the Upper Devonian Kettle Point Formation. Bartholomew et al. (2006) named this 6 m unit the Sarnia Formation.

Based on her examination of Hamilton Group strata of southwestern Ontario in outcrop and drillcores stored at the Oil, Gas & Salt Resources Library, London, Ontario, the present author agrees with the revised scheme. This division of Hamilton Group strata will be used in this thesis (Table 1-3a, Table 1-3b, Table 1-4).

1.3 Paleontological Background

Billings (1857) and Whiteaves (1889, 1898) described a few fossil species from the Hamilton Group of southwestern Ontario, including some brachiopods. However, the majority of paleontological studies on the Hamilton Group invertebrate fauna of southwestern Ontario of taxonomic nature were made on some taxa by members of the University of Michigan in the late 1940s to early-1980s. Studies included those on corals (Stumm, 1949), trilobites (Stumm, 1953), brachiopods (Ehlers and Wright, 1955, 1975; Wright and Wright, 1963; Wright, 1975), ostracods (Kesling, 1953a, b, c), echinoderms (Kesling, 1969, 1970, 1971, 1982a, b; Kesling and Wright, 1965), molluscs (George and Wright, 1959), and conodonts (Uyeno, et al., 1982). Southworth (1967) also figured some of the better-known fossils from the Arkona-Thedford area in an informal publication.

Formation	Stratigraphy Correlation			Main Lithology
	Nomenclature of Previous Authors	Bartholomew et al. (2006)		
Sarnia Formation		Sarnia Formation		Calcareous shale
Unnamed Formation	Upper Ipperwash Limestone (Cooper, et al., 1942; Wright and Wright, 1963)	Ipperwash Member		Limestone, Shale
Widder Formation		Petrolia Member	Upper Petrolia Submember	Shale, Limestone
	Lower Ipperwash Limestone (Wright & Wright, 1963)		Stony Point Submember	Wackestone, Packstone
	Golden Creek Beds (Wright & Wright, 1961)		Golden Creek Submember	Shale, Argillaceous limestone
	Unit 23 of the Widder Formation (Wright & Wright, 1961)		Unnamed Submember	Calcareous shale
	Unit 15-22 of the Widder Formation (Wright & Wright, 1961)		Rock Glen Submember	Packstone, Grainstone, Calcareous shale
	Unit 1-14 of the Widder Formation (Wright & Wright, 1961)	Thedford Member	Lower portion of the Widder Formation	Calcareous shale
	Unit 9 of the Hungry Hollow Formation (Mitchell, 1967)	Hungry Hollow Member	Coral zone/unit	Calcareous shale
	Units 6-8 of the Hungry Hollow Formation (Mitchell, 1967)		Encrinal unit	Packstone, Grainstone, Argillaceous limestone

Table 1-3a. The division of the middle and upper Hamilton Group strata in southwestern Ontario and the stratigraphy correlation between the previous work and Bartholomew et al. (2006).

Formation	Stratigraphy Correlation		Main Lithology
	Nomenclature of Previous Authors	Bartholomew et al. (2006)	
Arkona Shale Formation	Units 1-5 of the Hungry Hollow Fm. (Mitchell, 1967)	Arkona Shale Formation	Limestone, Calcareous shale, Shale
	Arkona Formation (Uyeno et al., 1982)		Calcareous shale, Argillaceous limestone
	Rockport Quarry Formation (Uyeno et al., 1982)		Argillaceous limestone, Shale
Bell Shale Formation	Bell Shale Formation (Uyeno et al., 1982)	Bell Shale Formation	Calcareous shale
	The top portion of the Dundee Formation (Uyeno et al., 1982)		Limestone

Table 1-3b. The division of the lower Hamilton Group strata in southwestern Ontario and the stratigraphy correlation between the previous work and Bartholomew et al. (2006).

Conodont Zone	Southwestern Ontario		
ansatus	Sarnia Fm.		
	Ipperwash Limestone (Unnamed Fm.)		
	Widder Fm.	Petrolia Mbr.	Upper petrolia Submbr.
			Stony Point Submbr.
—?— *rhenanus - varcus*			Golden Creek Submbr.
			Unnamed Submbr.
			Rock Glen Submbr.
		Thedford Mbr.	
—?— *timorensis*		Hungry Hollow Mbr.	Coral Unit
			Encrinal Unit
—?— *hemiansatus*	Arkona Shale Fm.		
—?— *ensensis*	Bell Shale Fm.		

Table 1-4. Stratigraphy of the Middle Devonian Hamilton Group of southwestern Ontario. The strata covered by gray shadow are in the subsurface (After Bartholomew et al., 2006).

Although Stumm and Wright (1958) compiled a faunal checklist of all the fossil invertebrates from the Thedford-Arkona-Ipperwash area of southwestern Ontario mentioned in previous publications, only a few common brachiopod species from the Hamilton Group of Ontario were systematically described by Whiteaves (1889, 1898), Ehlers and Wright (1955, 1975), Wright and Wright (1963), Tillman (1964), Driscoll et al. (1965), and Wright (1975). Thus, as one most diverse faunal element of the Hamilton Group of Southwestern Ontario, brachiopods as a whole are in dire need of taxonomic description in context with the stratigraphy. Furthermore, in the previous publications, owing to the lack of the modern taxonomy and detailed research on internal structures of brachiopods, brachiopod systematics has not been addressed beyond a superficial level.

1.4 Purpose of Study

This study has three main objectives:

1) To re-examine and revise the taxonomy of brachiopods from the exposed strata of the Hamilton Group of southwestern Ontario based on collections made in the course of this project and supplemental material from private and museum collections.
2) To revise the brachiopod stratigraphic distribution in exposed formations of the Hamilton Group in the Arkona-Thedford area of Ontario.
3) To define and compare brachiopod associations from the Hamilton Group strata in southwestern Ontario and equivalent strata in the Appalachian Basin and the

Michigan Basin, with the ultimate aim of detecting possible patterns of temporal and spatial differentiation in the brachiopod faunas of these separate basins and paleogeographic regions.

1.5 Method and Approach

1.5.1 Excavation Techniques and Brachiopod Collections in the Field

Outcrop sections were measured (with a tape measure), on the order of centimetres to decimetres, depending on the abundance of fossils and spacing of shell beds. Observations on the lithology, brachiopod fossil content and taphonomic characteristics of the measured outcrop sections, as well as the specific stratigraphic levels at which samples were collected were recorded. Wherever possible, individual brachiopod specimens and bulk samples of shell beds were collected *in situ* from fresh exposures and trenched sections.

1.5.2 Laboratory Work

In the laboratory, all the samples were catalogued according to stratigraphic occurrence. They were soaked overnight in a 10% sodium pyrophosphate solution to disaggregate clay particles and further cleaned by immersing in ultrasonic cleaning solution in an ultrasonic cleaner. For photographed specimens, a needle was used to clean any remaining matrix on the shells with the consideration that the specimens would not be damaged.

The illustrated specimens were coated with sublimated ammonium chloride and photographed using a Nikon D80 digital SLR camera. Five photos (dorsal, ventral, lateral, posterior, and anterior views) were taken for a complete external representation of one species.

For the purpose of studying internal structures, transverse serial sections of the brachiopod representatives have been made using a Croft parallel grinder. The selected specimen was given a thin beeswax coating, then was mounted to the grinder specimen disk by pouring some hot melted beeswax surrounding the specimen. After the beeswax surrounding the specimen cooled down and hardened, the specimen was fastened to the grinder. Prior to grinding the specimen, the initial shell length was recorded. Specimens were usually ground at 0.1 to 0.3 mm increments. When each specimen was ground from its posterior portion, a transverse section was produced and the distance from the posterior portion (generally the beak of the ventral valve) to the transverse section was recorded. The specimen was removed from the grinder and one or more drops of 5% hydrochloric acid solution, specific amount depending on the size of the transverse section, was applied to the polished transverse surface. After a 5-10 second etching, the specimen was rinsed with distilled water and dried under pressurized air. Acetone was then applied to the dry transverse surface and an acetate sheet was immediately put on the transverse surface before the acetone completely evaporated. One or two minutes later, when the acetate sheet had become adhered to the etched surface, it was peeled off from the sample. For each specimen, 20-50 acetate peels were made, the specific number depending on the dimensions of internal structures and the preservation quality of the selected specimens. This technique allows all the details of internal structures of the specimen to be imprinted on the acetate peel sections.

1.5.3 Brachiopod Fauna Data Analysis

To compare and analyze the brachiopod faunas of the Hamilton Group from the study area with those of equivalent strata in the Appalachian Basin and the Michigan Basin, multivariate analyses using PAST 1.90 (Hammer and Harper, 2006, 2007) were present. In other words, Q-mode (taxa as variables), R-mode (localities/ages as variables) cluster analyses and principal component analysis (PCA) were performed. Furthermore, four faunal similarity analyses (i.e., Jaccard similarity, Dice similarity, Simpson's coefficient of similarity, and Raup-Crick similarity indices) within each cluster were accomplished. For the details of these methods, please see the methods part of Chapter 3.

1.6 Collecting Localities

The bedrock distribution of the Middle Devonian Hamilton Group of southwestern Ontario is shown in Figure 1-4. It should be noted, however, that actual exposures are restricted to the Arkona-Thedford-Ipperwash area, which is ~ 19.3 km in breadth and extends about 16 km southward from the southern shore of Lake Huron; this area, located mainly within Bosanquet Township (Lambton County), extends eastward into West Williams Township (Middlesex County). As Wright and Wright (1961) mentioned, most of the fossil-bearing Hamilton Group outcrops are exposed in gorges cut by the Ausable River (which flows through the eastern part of the Arkona-Thedford-Ipperwash area), and its tributary creeks. Additional exposures are found in roadside ditches and clay quarries within the area.

The 10 brachiopod collecting localities are as follows (Figure 1-5 and Figure 1-6):

Collecting locality 1. South Pit, Hungry Hollow, Arkona, West Williams Township, Middlesex County, southwestern Ontario (Pl. 1-1, figs. 1-5)

This is an abandoned clay quarry, where ~ 8.00 m of the upper Arkona Shale and part of the Hungry Hollow Member (Widder Formation) are exposed. The 0.43-0.58 m of the encrinal unit of the Hungry Hollow Member is well-exposed; however, the coral unit of the Hungry Hollow Member is poorly preserved due to glacial reworking and quarrying activity.

Collecting locality 2. North Pit, Hungry Hollow (Pl. 1-2, figs. 1-5)

This quarry, abandoned for over a decade, has recently been re-opened. Due to the quarrying, the exposures are unstable. However, in the summer of 2007, up to ~ 9.00 m of the upper Arkona Shale was exposed, together with ~ 1.3 m of the entire Hungry Hollow Member (Widder Formation).

Collecting locality 3. North bank of the Ausable River, Hungry Hollow (Pl. 1-3, figs. 1-6)

The outcrop occurs as a steep slope with 1.00-2.00 m of the upper Arkona Shale, the whole Hungry Hollow Member (1.30-1.55m), and ~5.00 m of the lower portion of the Thedford Member of the Widder Formation exposed.

Collecting locality 4. No.4 Hill, Arkona, West Williams Township, Middlesex County (Pl. 1-4, figs. 1-4)

This outcrop exposes approximately 6.20 m of the upper Arkona Shale, the entire Hungry Hollow Member, the entire Thedford Member (~ 10.00 m), and ~ 3.72 m of the lower portion of the Petrolia Member of Widder Formation.

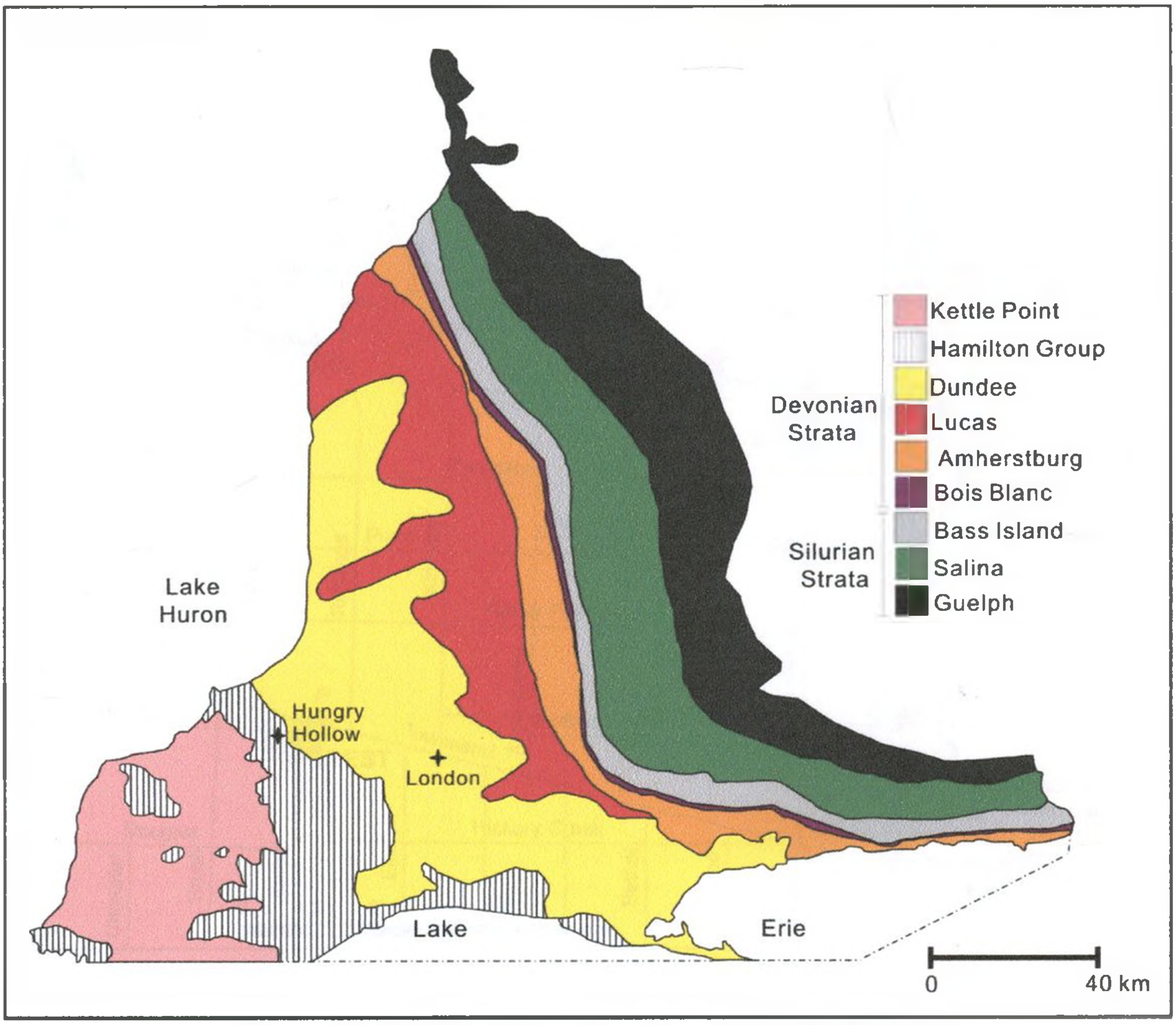


Fig. 1-4. Geological map of southwestern Ontario (After Telford, 1975).

Fig. 1-5. The geographic map showing the 10 brachiopod collecting localities which have been mentioned in this thesis.

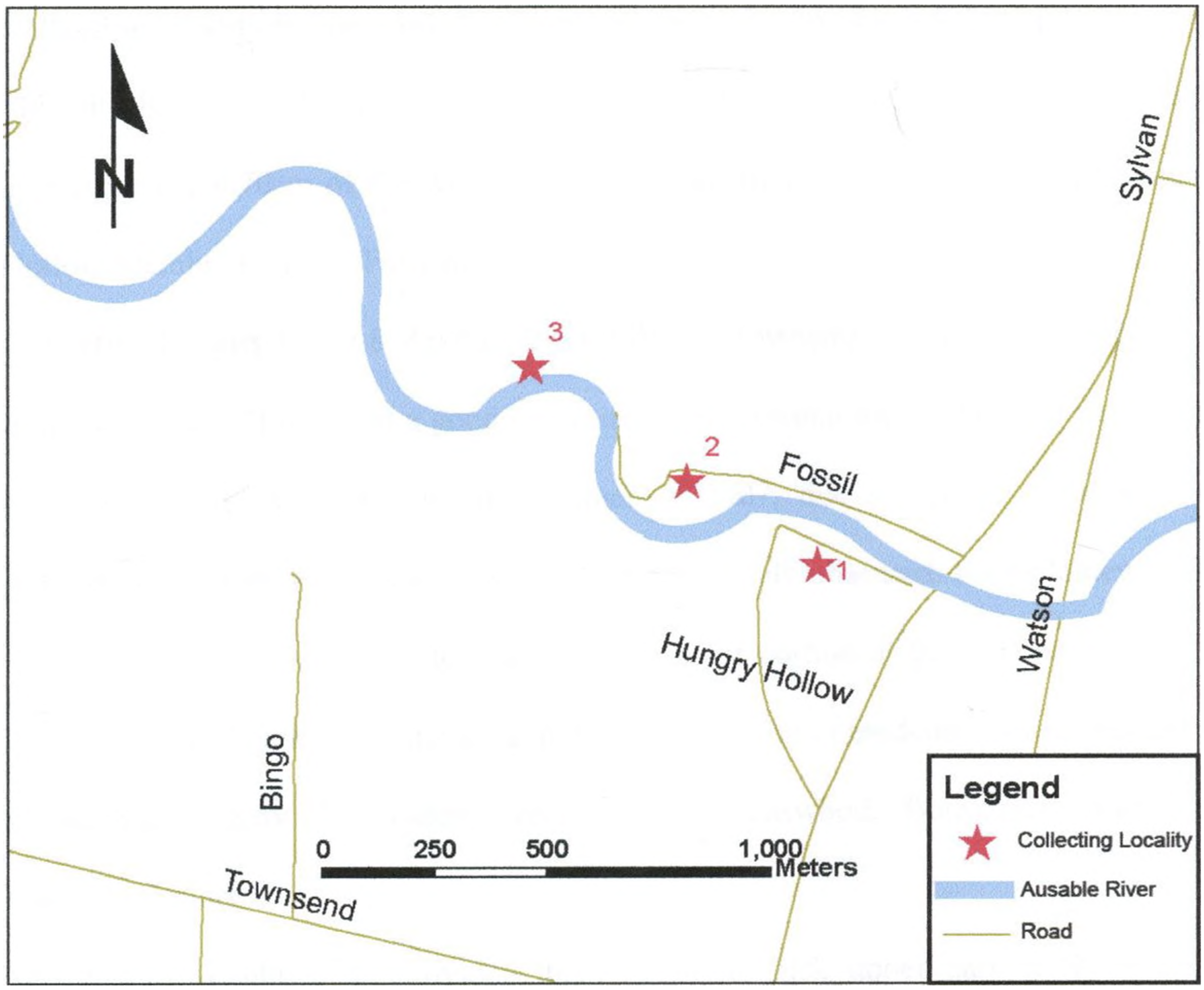


Fig. 1-6. The enlarged geographic map showing the brachiopod collecting localities 1, 2, and 3.

Collecting locality 5. Tile Yard, Thedford, Lambton County (Pl. 1-5, figs. 1-3)

This site is an abandoned quarry converted to a lumber yard. The outcrop exposes approximately 4.70 m of the Arkona Shale and approximately 1.50 m of the Hungry Hollow Member (Widder Formation).

Collecting locality 6. Lot 8, Arkona, West Williams Township, Middlesex County

Southworth (1967) reported a good exposure of the Arkona Shale about 40 years ago. However, when we visited in the summer of 2007, due to human activities and re-establishment by vegetation, it was almost completely obscured. Bartholomew et al. (2006) described this outcrop to belong to the upper portion of the Arkona Shale, a < 0.5 m interval of dark-grey mudstone and overlying ~ 5m of medium-grey mudstone.

Collecting locality 7. Golden Creek, near Ravenswood, Bosanquet Township, Lambton County

Wright and Wright (1961) divided this ~ 3.20 m thick upper part of the Widder Formation into 8 units (Unit A through Unit H). Due to human activities in the past 46 years, by the summer of 2007, the outcrop almost disappeared except that some brachiopod species scattered on the banks of the creek.

Collecting locality 8. Shore of Lake Huron, Stony Point, Bosanquet Township, Lambton County (Pl. 1-6, figs. 1-4)

The outcrop at Stony Point belongs to the Stony Point submember of the Petrolia Member (Widder Formation). Wright and Wright (1963) described ~ 2.08 m thick interval of limestone and divided the interval into 8 units mainly based on rock color and slight difference in lithology. In the summer of 2007, ~ 0.20 m thick large blocks of fossiliferous limestone (wackestone and packstone) were present here.

Collecting locality 9. Shore of Lake Huron, Kettle Point, Bosanquet Township, Lambton County (Pl. 1-7, figs. 1-5)

Large blocks of rock dredged from boat slips have provided samples of the Ipperwash Member (unnamed formation). Wright and Wright (1963) divided the ~0.82 m thick interval represented in these blocks into three units: the lower unit contains ~ 0.39 m of dark grey limestone; the middle unit comprises 0.18 m of weathered brown shale; and the top unit consists of 0.25 m thick thin-bedded limestone.

Collecting locality 10. Rock Glen, Arkona, West Williams Township, Middlesex County (Pl. 1-8, figs. 1-3)

At Rock Glen, approximately 12.10 m of the Arkona Shale, approximately 1.30 m of the entire Hungry Hollow Member (Widder Formation), and approximately 14.90 m of strata (Widder Formation) overlying the Hungry Hollow Member are exposed.

Plate 1-1

Fig. 1. The outcrop at South Pit, Hungry Hollow. Approximately 8.00 m of the upper Arkona Shale and 0.43-0.58 m of the overlying Encrinal Unit of the Hungry Hollow Member (Widder Formation) are well-exposed; The Coral Unit of the Hungry Hollow Member, is poorly preserved due to glacial reworking and quarrying activity.

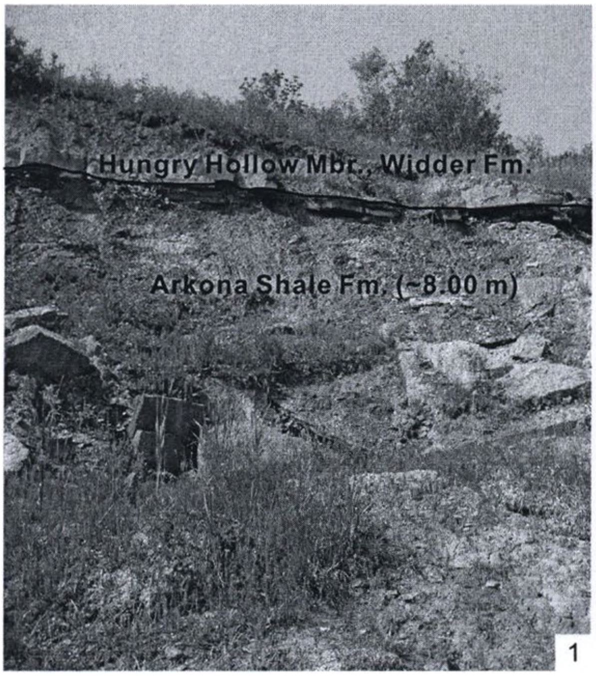
Fig. 2. Close-up of the Hungry Hollow Member (Widder Formation) and the uppermost portion of the Arkona Shale Formation.

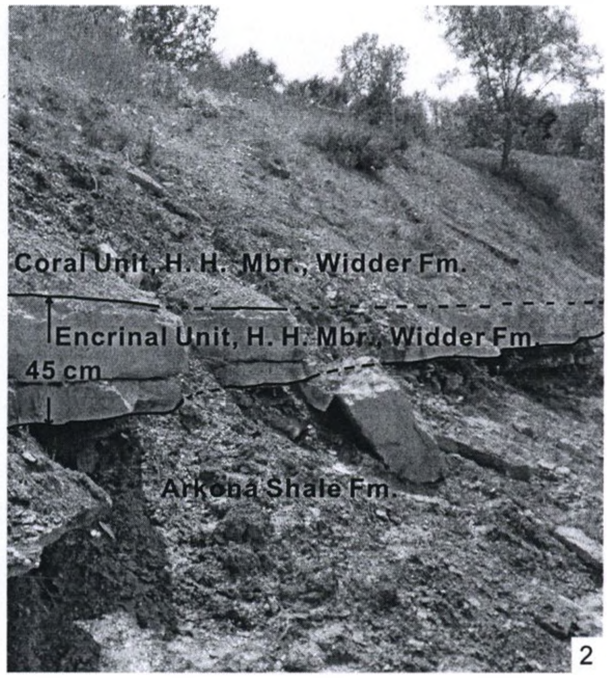
Fig. 3. Close-up of the Hungry Hollow Member (Widder Formation).

Fig. 4. Fossil pavement in the upper part of the Arkona Shale Formation.

Fig. 5. Flattened moulds of *Leiorhynchus kelloggi* Hall, 1867 in black shale (Unit 5 of Mitchell (1967)).

Pl. 1-1


Hungry Hollow Mbr., Widder Fm.
Arkona Shale Fm. (~8.00 m)
1


Coral Unit, H. H. Mbr., Widder Fm.
Encrinal Unit, H. H. Mbr., Widder Fm.
45 cm
Arkona Shale Fm.
2


Coral Unit: Unit 9 (Mitchell, 1967)
Encrinal Unit:Units 6-8 (Mitchell, 1967)
10 cm
Units 4-5 (Mitchell, 1967)
Units 1-3 (Mitchell, 1967)
3


Mucrospirifer mucronatus (Conrad, 1841)
Devonochonetes arkonensis n. sp.
4


Leiorhynchus kelloggi Hall, 1867
5

Plate 1-2

Fig. 1. Part of the outcrop on the west side of the North Pit, Hungry Hollow. Approximately 6.50 m of upper part of Arkona Shale is exposed.

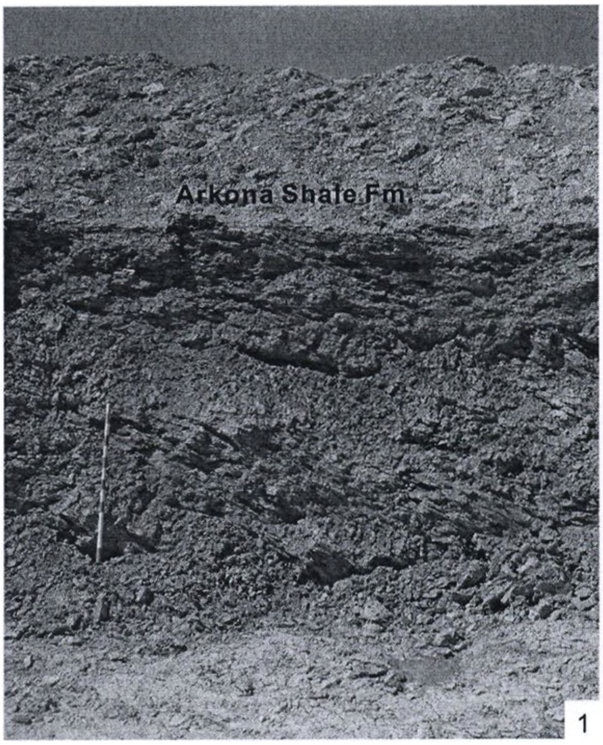
Fig. 2. Part of the outcrop in the north side of the North Pit, Hungry Hollow. The top portion of the Arkona Shale Formation and the overlying entire Hungry Hollow Member (Widder Formation) are exposed. The top of the hammer is the contact between the Arkona Shale Formation and the overlying Hungry Hollow Member (Widder Formation).

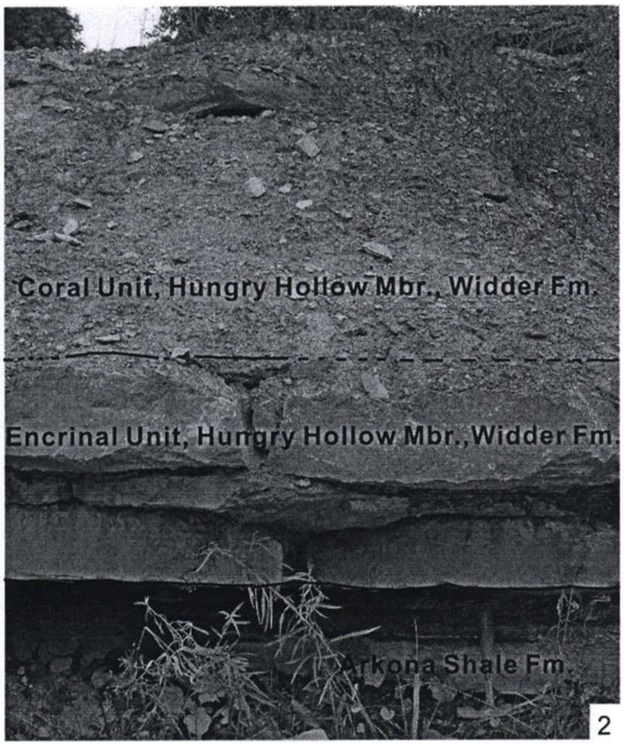
Fig. 3. Presence of limestone nodules in the Arkona Shale Formation. The bed containing this nodule is approximately 8.50 m lower than the contact between Arkona Shale and the Hungry Hollow Member (Widder Formation).

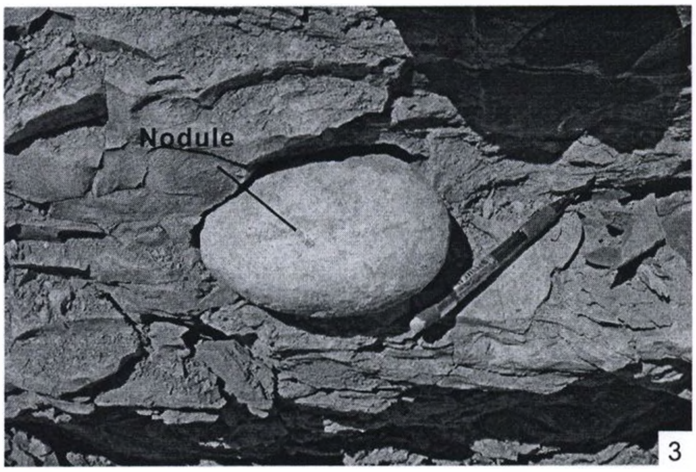
Fig. 4. Example of *Mucrospirifer mucronatus* (Conrad, 1841) in life position in Arkona Shale Formation.

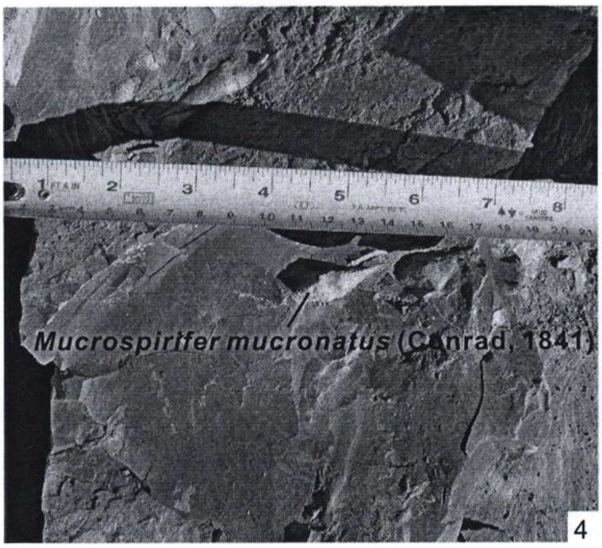
Fig. 5. A fossil pavement of *Mucrospirifer-Devonochonetes-Tentaculites* is shown on a slab, from a level approximately 8.00 m below the contact between the Arkona Shale Formation and the Hungry Hollow Member (Widder Formation).

Pl. 1-2


Arkona Shale Fm.
1


Coral Unit, Hungry Hollow Mbr., Widder Fm.
Encrinal Unit, Hungry Hollow Mbr., Widder Fm.
Arkona Shale Fm.
2


Nodule
3


Mucrospirifer mucronatus (Conrad, 1841)
4


Mucrospirifer mucronatus (Conrad, 1841)
Devonochonetes arkonensis n. sp.
Tentaculites sp.
5

Plate 1-3

Fig. 1. Outcrop on the north bank of the Ausable River at Hungry Hollow. The contact between the Arkona Shale Formation and the Widder Formation, and the contact between the Hungry Hollow Member (Widder Formation) and the Thedford Member (Widder Formation) are marked by the lower and upper dashed lines, respectively.

Fig. 2. Close-up of the top portion of the Arkona Shale Formation and its contact with Hungry Hollow Member (Widder Formation). The contact is marked by the uppermost dashed line.

Fig. 3. The grey calcareous shale unit (Unit 4 of Mitchell (1967)) and the black laminated shale (Unit 5 of Mitchell (1967)). Contact between these units is marked by the middle dashed line.

Fig. 4. Crushed *Leiorhynchus kelloggi* Hall, 1867, and their moulds, in the black laminated shale (Unit 5 of Mitchell (1967)).

Fig. 5. Coral Unit of the Hungry Hollow Member (Widder Formation) and the lower part of the Thedford Member (Widder Formation). Contact between these two members is marked by the dashed line.

Fig. 6. Close-up of the contact in Fig. 5. Corals are very abundant in Coral Unit but absent in the overlying calcareous shale beds of the Thedford Member.

Pl. 1-3

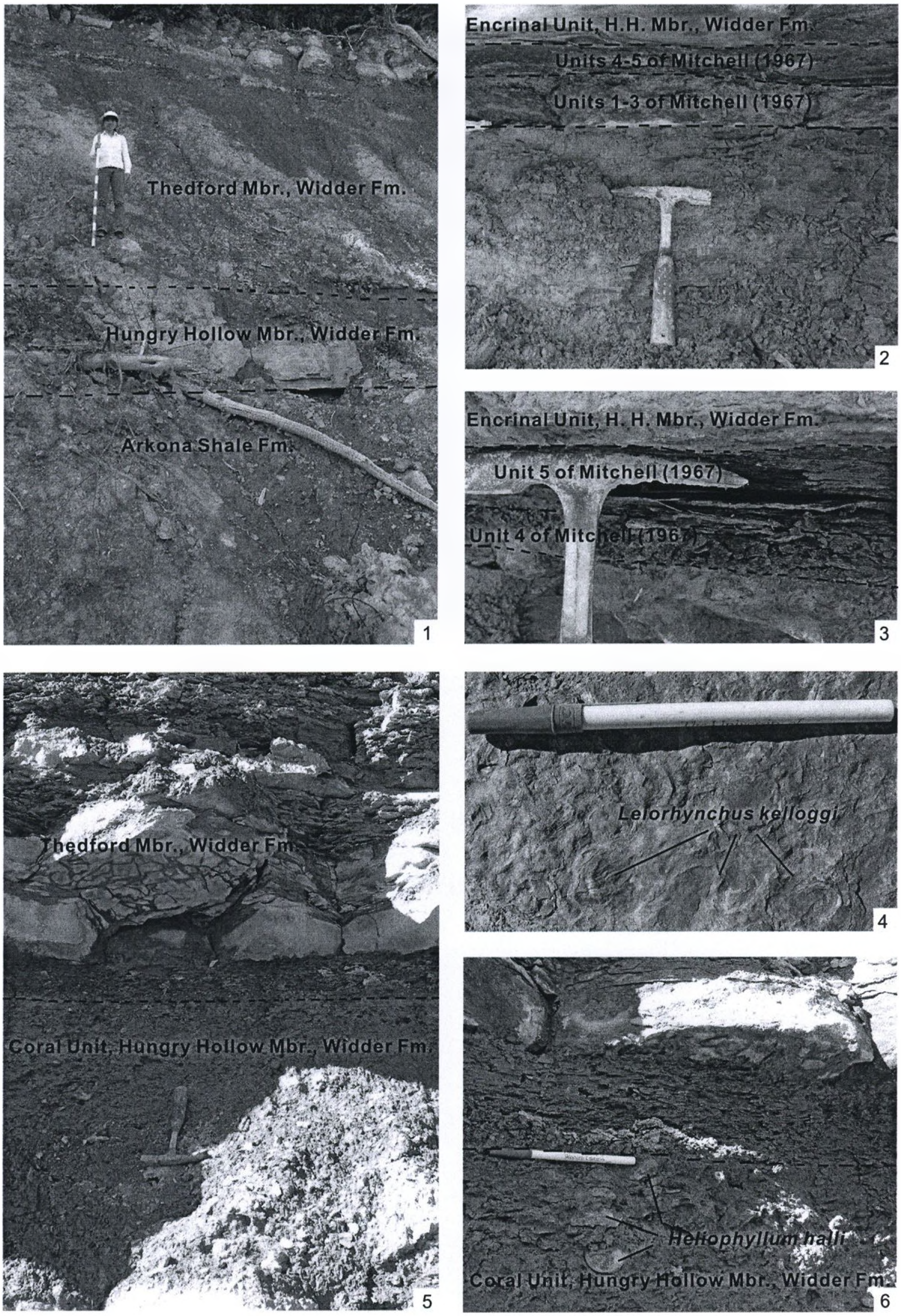

Thedford Mbr., Widder Fm.
Hungry Hollow Mbr., Widder Fm.
Arkona Shale Fm.
1
Encrinal Unit, H.H. Mbr., Widder Fm.
Units 4-5 of Mitchell (1967)
Units 1-3 of Mitchell (1967)
2
Encrinal Unit, H. H. Mbr., Widder Fm.
Unit 5 of Mitchell (1967)
Unit 4 of Mitchell (1967)
3
Lelorhynchus kelloggi
4
Thedford Mbr., Widder Fm.
Coral Unit, Hungry Hollow Mbr., Widder Fm.
5
Heliophyllum halli
Coral Unit, Hungry Hollow Mbr., Widder Fm.
6

Plate 1-4

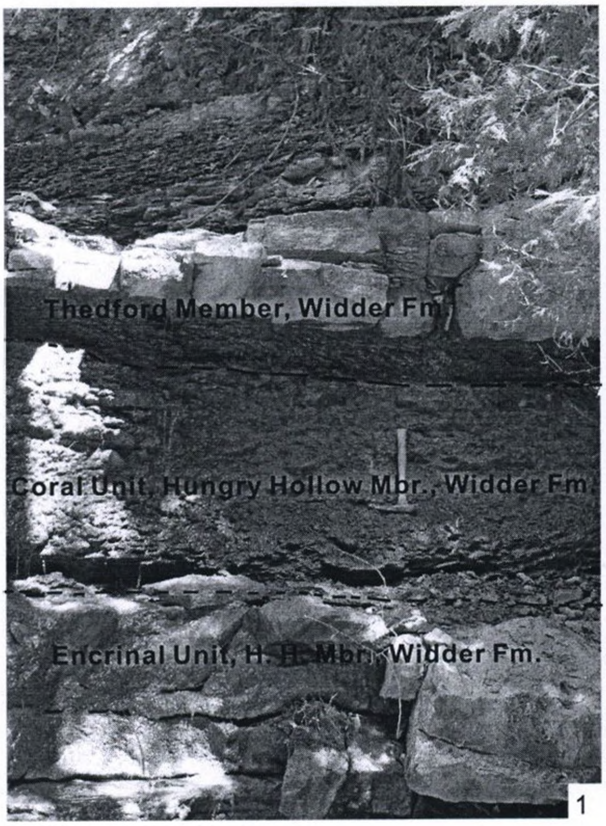
Fig. 1. This outcrop is located near the falls of No. 4 Hill. The entire basal member, ~ 1.35 m of the Hungry Hollow Member (Widder Formation) and the overlying Thedford Member (Widder Formation) show up in this figure. The contact between the Encrinal Unit and the Coral Unit is marked by the lower dashed line. The contact between the Thedford Member and the Hungry Hollow Member is marked by the upper dashed line.

Fig. 2. This outcrop is at the falls of No. 4 Hill. Approximately 8.00 m of the Thedford Member (Widder Formation) is exposed.

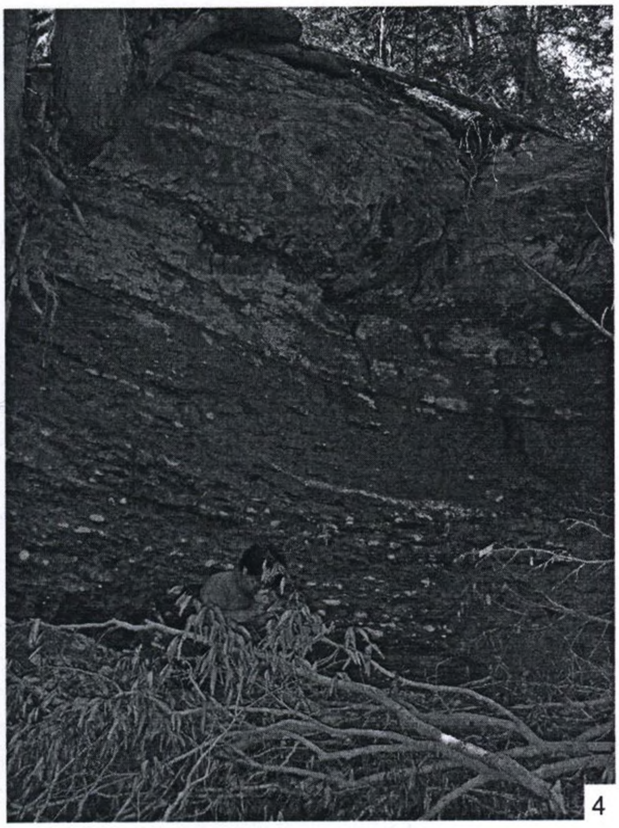
Fig. 3. Close-up of the lower part of the outcrop at the falls of No. 4 Hill. It consists of gray calcareous shale with an exceptional abundance of *Mucrospirifer mucronatus* (Conrad, 1841).

Fig. 4. The top part of outcrop in the glen at No. 4 Hill. The entire Rock Glen Submember (Petrolia Member, Widder Formation) is exposed.

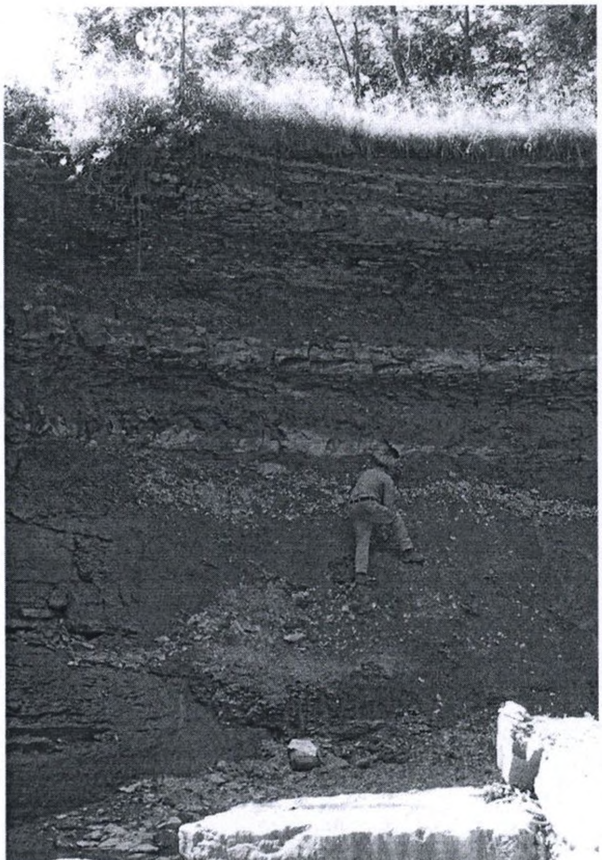
Pl. 1-4


Thedford Member, Widder Fm.
Coral Unit, Hungry Hollow Mbr., Widder Fm.
Encrinal Unit, H. H. Mbr., Widder Fm.

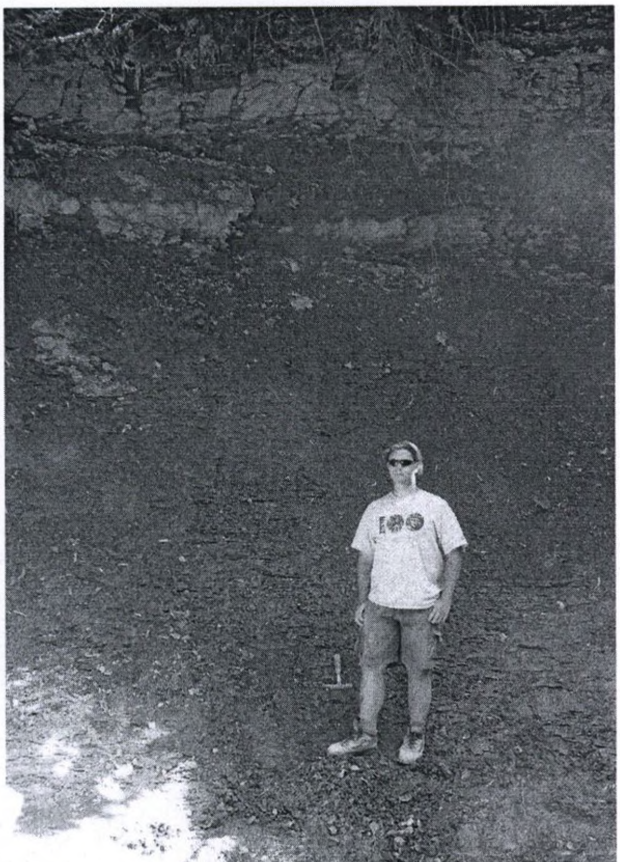
1



4



2



3

Plate 1-5

Fig. 1. The north part of the outcrop at Tile Yard, Thedford. The uppermost 4.7 m of the Arkona Shale Formation, the entire Encrinal Unit (0.43 m ~ 0.55 m in thickness) of the Hungry Hollow Member (Widder Formation), and part of the Coral Unit of the Hungry Hollow Member (Widder Formation) are exposed. The contact between the Arkona Shale Formation and the overlying Hungry Hollow Member (Widder Formation) is marked by the dashed line.

Fig. 2. The south part of the outcrop at Tile Yard, Thedford. The uppermost part of the Arkona Shale Formation and the entire Hungry Hollow Member (Widder Formation) are exposed at this locality. The contact between the Arkona Shale Formation and the Hungry Hollow Member (Widder Formation) is marked by the lower dashed line. In the Hungry Hollow Member, the Encrinal Unit and the overlying Coral Unit is marked by the upper dashed line.

Fig. 3. Burrows preserved on the bottom surface of a slab from Unit 1 of Mitchell (1967).

Pl. 1-5

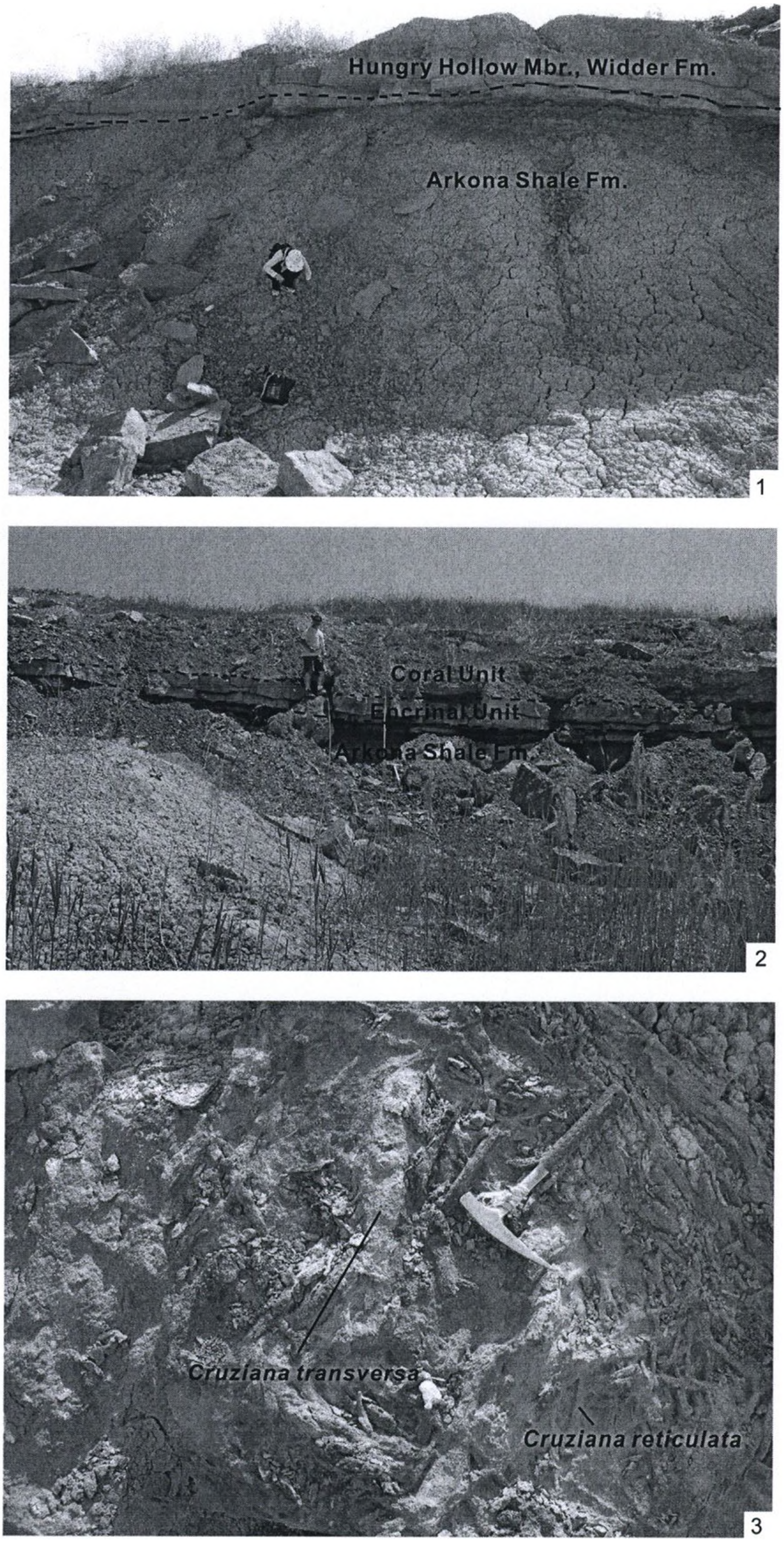

Hungry Hollow Mbr., Widder Fm.
Arkona Shale Fm.
1
Coral Unit
Encrinal Unit
Arkona Shale Fm.
2
Cruziana transversa
Cruziana reticulata
3

Plate 1-6

Fig. 1. View of limestone blocks from the Stony Point Submember (Petrolia Member, Widder Formation) at Stony Point, shore of Lake Huron.

Fig. 2-4. Some brachiopod fossil samples in the limestone blocks at Stony Point.

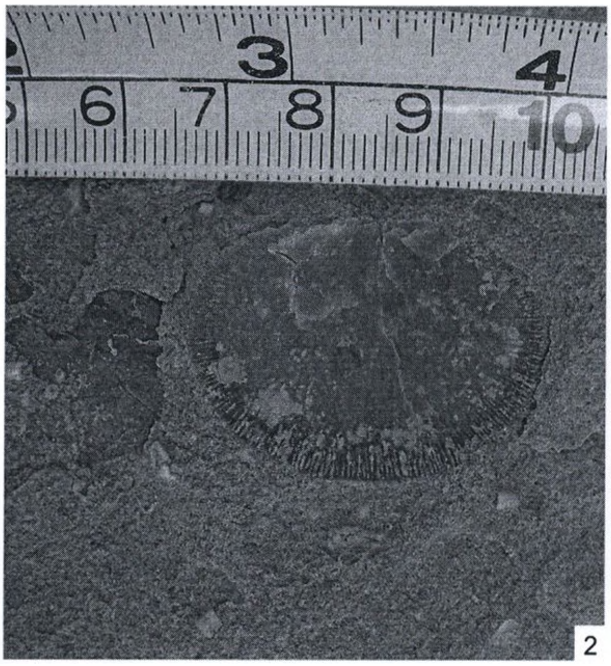
Fig. 2. *Rhipidomella penelope* (Hall, 1860)

Fig. 3. *Mucrospirifer mucronatus* (Conrad, 1841)

Fig. 4. *Spinocyrtia ravenswoodensis* Ehlers & Wright, 1955

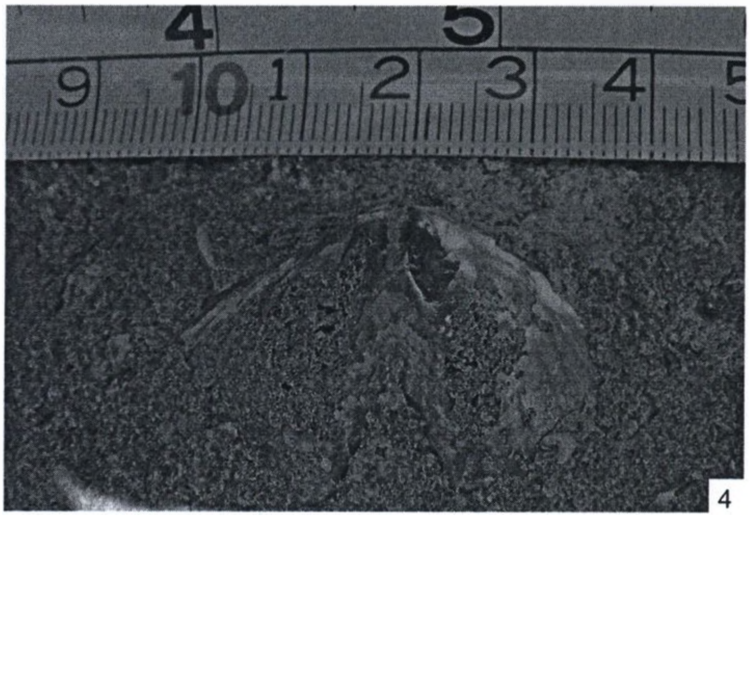
Pl. 1-6

1



2

3



4

Plate 1-7

Fig. 1. View of the Ipperwash Limestone (unnamed formation) dredged from boat slips at Kettle Point, shore of Lake Huron.

Fig. 2-5. Some brachiopod fossil samples in the Ipperwash Limestone blocks at Kettle Point.

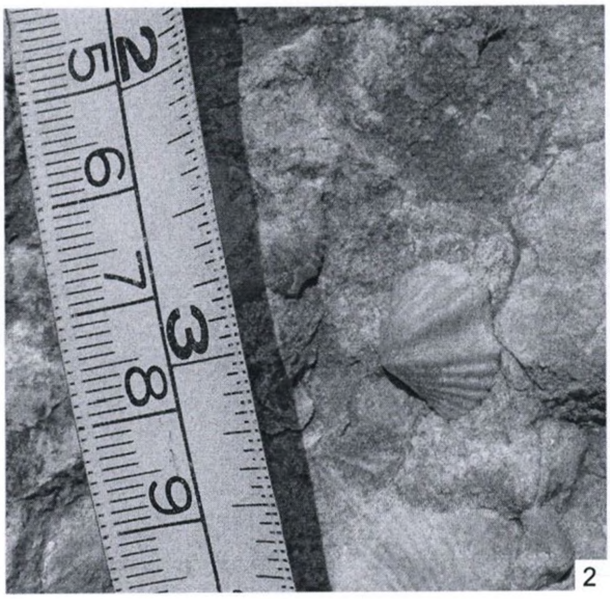
Fig. 2. *Cyrtina staufferi* Wright & Wright, 1963.

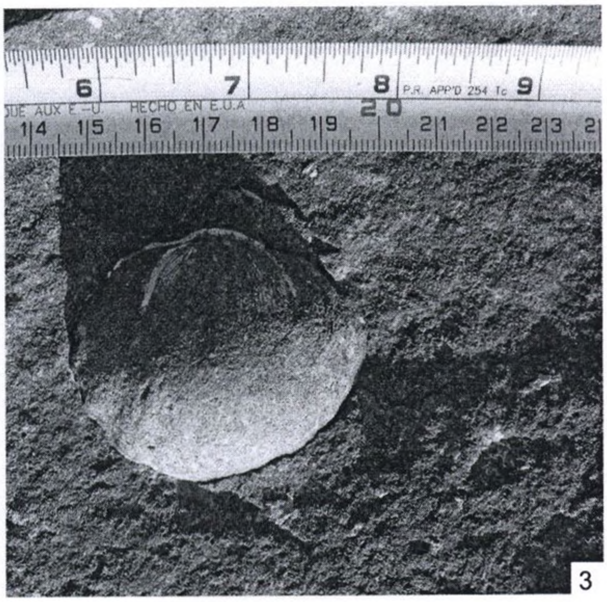
Fig. 3. Mould of *Megastrophia concava* (Hall, 1857)

Fig. 4. *Strophodonta* (*Strophodonta*) *demissa* (Conrad, 1842)

Fig. 5. *Spinocyrtia granulosa* (Conrad, 1839)

Pl. 1-7


2


P.R. APP'D 254 Tc
HECHO EN E.U.A
3


1


MADE IN USA
FABRIQUE AUX E.-U.
HECHO EN E.U.A
4


5

Plate 1-8

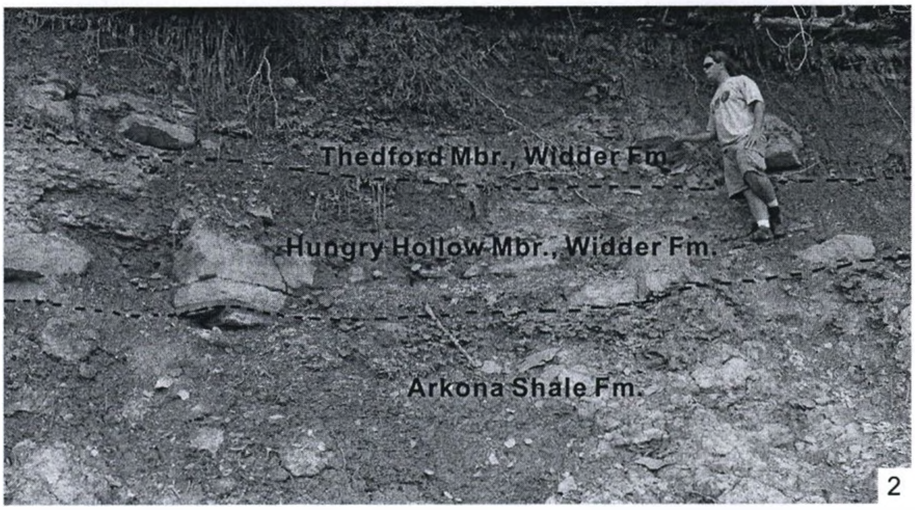
Fig. 1. View of the Rock Glen exposure of the Hamilton Group strata. Approximately 12.10 m of the Arkona Shale Formation, approximately 1.30 m of the entire Hungry Hollow Member (Widder Formation), and approximately 0.85 m of the Thedford Member (Widder Formation) are exposed. The contact between the Arkona Shale Formation and the Widder Formation is marked by the lower dashed line. Within the Widder Formation, the contact between the Hungry Hollow Member and the overlying Thedford Member is marked by the upper dashed line.

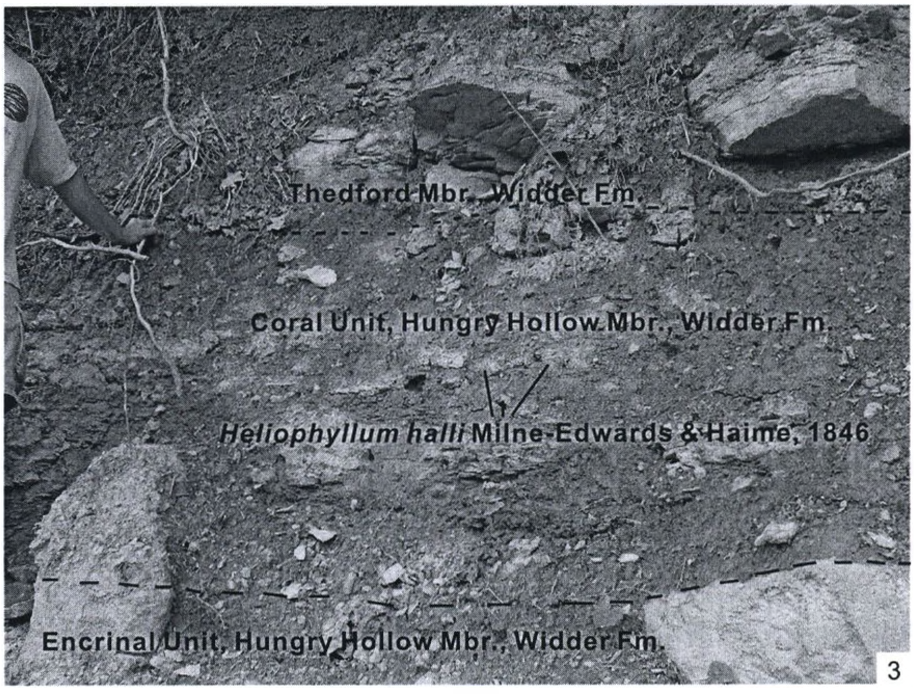
Fig. 2. Close-up of the upper part of the Rock Glen outcrop. The lower dashed line and the upper dashed line represent same contacts as in Fig. 1.

Fig. 3. Close-up of the same outcrop but focusing on the Hungry Hollow Member (Widder Formation). Corals are quite abundant in the Coral Unit of the Hungry Hollow Member, but absent in the overlying shale beds of the Thedford Member. The contact of these two members is marked by the upper dashed line. Within the Hungry Hollow Member, the contact between the Coral Unit and the underlying Encrinal Unit is marked by the lower dashed line.

Pl. 1-8


Thedford Mbr., Widder Fm.
H. H. Mbr., Widder Fm.
Arkona Shale Fm.
1


Thedford Mbr., Widder Fm.
Hungry Hollow Mbr., Widder Fm.
Arkona Shale Fm.
2


Thedford Mbr., Widder Fm.
Coral Unit, Hungry Hollow Mbr., Widder Fm.
Heliophyllum halli Milne-Edwards & Haime, 1846
Encrinal Unit, Hungry Hollow Mbr., Widder Fm.
3

Chapter 2: Taxonomy and Biostratigraphy of Brachiopods from the Middle Devonian Hamilton Group of Southwestern Ontario

2.1 Introduction

The late Middle Devonian (Givetian) Hamilton Group of southwestern Ontario is well known worldwide among fossil collectors for its diverse, abundant and well-preserved invertebrate fauna. Despite their undoubted value as an archive of paleontological resource, the Hamilton Group fauna in southwestern Ontario has been largely ignored over the past few decades (Tsujita et al., 2001). This has been especially true for the brachiopods which, despite being among the most prominent faunal elements in Hamilton Group exposures in Ontario, have been identified primarily via comparisons with brachiopod specimens from Hamilton Group exposures in the United States. This is no more apparent than in Stumm and Wright's (1958) checklist of brachiopod (and other invertebrate) species in the well-known Hamilton Group exposures of the Arkona-Thedford-Ipperwash area of southwestern Ontario. Although Stumm and Wright (1958) compiled a faunal checklist of all the mentioned fossil invertebrates, fewer than 30 brachiopod species from the Hamilton Group of Ontario were described by Whiteaves (1889, 1898), Ehlers and Wright (1955, 1975), Wright and Wright (1963), Tillman (1964), Driscoll et al. (1965), and Wright (1975). Furthermore, in the above previous work, only some brachiopod species which were assigned to the genera *Mucrospirifer*, *Cyrtina*, and *Spinocyrtia*, have been systematically described with detailed comparison in context with stratigraphy. Owing to the lack of detailed study on internal structures of brachiopods, existing systematic descriptions of these taxa lack the level of detail now deemed essential for the classification of fossil brachiopods. In other words, the systematics of Hamilton Group brachiopod species in general have not yet been investigated beyond a superficial level, thus necessitating a thorough re-examination and description of these taxa.

The main objectives of this chapter are: 1) to provide detailed systematic descriptions of the brachiopod taxa known to occur specifically in the exposed Hamilton Group strata of southwestern Ontario in context with the stratigraphy, 2) to revise the brachiopod stratigraphic distribution in the Hamilton Group strata exposed in southwestern Ontario that can ultimately be used for biogeographic investigations of Middle Devonian brachiopods (Chapter 3).

2.2 Systematic Paleontology

Some of the figured specimens are housed in the Department of Earth Sciences, the University of Western Ontario (W), London, Ontario, Canada; all others are housed in the Museum of Paleontology, the University of Michigan (UMMP), Ann Arbor, Michigan, U. S. A.

Descriptions of species are presented in the following format: Shell size (large, > 30 mm; medium, 20-30 mm; small, < 10 mm in average diameter); Shape; Ventral valve exterior; Ventral valve interior; Dorsal valve exterior; Dorsal valve interior.

The abbreviations used in this chapter are as follows: W: shell width; L, shell length; T, shell thickness; W_1, width of hinge line; H_1, height of ventral interarea; CN, the number of costellae per 2 mm where it is 2 mm away from hinge line anteriorly; STD, standard deviation; MIN, minimum; and MAX, maximum; N, the number of specimens; W, University of Western Ontario; UMMP, University of Michigan, Museum of Paleontology; GSC, Geological Survey of Canada; NYSM, New York State Museum; USNM, United States National Museum; BMS, Buffalo Museum of Science; AMNH, American Museum of Natural History; I, New York State Geological Survey, Albany.

Phylum BRACHIOPODA Duméril, 1806

Subphylum LINGULIFORMEA Williams et al., 1996

Class LINGULATA Gorjansky & Popov, 1985

Order LINGULIDA Waagen, 1885

Superfamily LINGULOIDEA Menke, 1828

Family LINGULIDAE Menke, 1828

Genus *Lingula* Bruguiére, 1797

Type species: *Lingula anatina* Lamarck, 1801, exact horizon and locality unknown, exact age unknown.

Lingula? *thedfordensis* Whiteaves, 1889

Pl. 2-1, figs. 1-5

1889 *Lingula thedfordensis* Whiteaves, p. 111, pl. 15, fig. 1.

1902 *Lingula thedfordensis* Whiteaves; Shimer & Grabau, p. 182.

1958 *Lingula thedfordensis* Whiteaves; Stumm & Wright, p. 105, 114.

Types. Holotype GSC 3673 and paratype GSC 3673a, exact locality and horizon unknown, Hamilton Group (Middle Devonian), near Thedford, Ontario, Canada.

Description. Shell small to medium, broadly subelliptical, length approximately one third greater than the maximum width; surface of valves marked with numerous radiating plications, crossed by fine, concentric, raised growth lines.

Ventral valve moderately convex; ventral pseudointerarea with wide triangular ventral groove for passage of pedicle; ventral pseudointerarea vestigial, lacking flexure lines.

Ventral interior unknown.

Dorsal valve slightly convex; dorsal pseudointerarea undivided.

Dorsal interior unknown.

Material. Total 8 incomplete specimens.

Occurrence. Coral Unit, Hungry Hollow Member, Widder Formation; Arkona-Thedford-Ipperwash area, southwestern Ontario.

Discussion. According to Holmer and Popov (2000, p. 36), the age range of the genus *Lingula* is Tertiary (or possibly Cretaceous) to Holocene. The Hamilton Group lingulids described here are difficult to assign to any particular genus due to their incomplete shells and lack of interior characters and can therefore be only questionably assigned to the genus *Lingula*.

The eight incomplete specimens are similar to *Lingula thedfordensis* Whiteaves, 1889 in terms of exterior characters. Another species, *L. ligea* Hall, from the shales of the upper part of the Hamilton Group of New York State, was reported by Hall (Hall, 1867, p. 7-8, Pl. 1, fig. 2). However, due to its broader subelliptical profile, *Lingula*? *thedfordensis* can be easily distinguished from *L. ligea* whose shell length is twice its width. *L. spatulata* from unit 9 of the Silica Formation of Ohio (Hoare, et al., 1969, p. 264, 266, Pl. 1, figs. 3-5) is distinguished from *L.? thedfordensis* by the fact that its shell is smaller and more elongate (average width: 2.04 mm; average length: 3.56 mm) than the latter's shell.

Superfamily DISCINOIDEA Gray, 1840

Family DISCINIDAE Gray, 1840

Genus *Orbiculoidea* D'Orbigny, 1847

Type species: *Orbicula forbesii* Davidson, 1848, Wenlock Limestone (Silurian), Dudley, U. K..

Orbiculoidea doria (Hall, 1863)

Pl. 2-1, fig. 6

1863a *Discina doria* Hall, p. 26.

1867 *Discina doria*; Hall, p. 19, pl. 2, figs. 19-22.

1889 *Discina doria*; Nettelroth, p. 32.

1897 *Orbiculoidea doria* Schuchert, p. 228.

1901 *Orbiculoidea doria*; Kindle, p. 579-580, pl. 3, fig. 7.

1902 *Orbiculoidea doria*; Shimer & Grabau, p. 182.

1911 *Orbiculoidea wardi* Cleland, p. 85, pl. 12, figs. 14-16.

1915 *Orbiculoidea doria*; Stauffer, P. 234.

1958 *Orbiculoidea doria*; Stumm & Wright, p. 105, 114.

1965 *Orbiculoidea* cf. *O. doria* Greisemer, p. 251, pl. 1, figs. 10-11.

1969 *Orbiculoidea doria*; Hoare & Steller, p. 267, pl. 1, figs. 10-13.

Types. The original description of this taxon by Hall (1863) included neither illustrations nor a designated holotype, but did mention that the original specimens on which the description was based were from rocks of the Hamilton Group. The collecting localities were noted as: 1) Hamilton, Madison County, Iowa; 2) the East shore of Seneca Lake, New York; and 3) Canada West. Original types cannot be traced from previous references.

Description. Shell medium to large, oblate or subcircular.

Ventral valve unknown.

Dorsal valve moderately convex, conical to subconical, apex elevated, subterminal; surface of dorsal valve marked by numerous coarse concentric growth lines.

Dorsal interior unknown.

Material. Total 4 incomplete dorsal valves.

Occurrence. Coral unit, Hungry Hollow Member, Widder Formation; Arkona-Thedford-Ipperwash area, southwestern Ontario.

Discussion. Orbiculoidea doria (Hall, 1863) differs from *O. telleri* Cleland, 1911 from the Middle Devonian rocks of southeastern Wisconsin (Griesemer, 1965, p. 252, pl. 1, figs. 13-15) in its elevated dorsal apex and more strongly developed growth lines.

Subphylum CRANIIFORMEA Popov et al, 1993

Class CRANIATA Williams et al., 1996

Order CRANIIDA Waagen, 1885

Superfamily CRANIOIDEA Menke, 1828

Family CRANIIDAE Menke, 1828

Genus *Petrocrania* Raymond, 1911

Type species: *Craniella meduanensis* Oehlert, 1888, exact locality and horizon unknown (Lower Devonian), Ferques, France.

Petrocrania hamiltoniae (Hall, 1860)

Pl. 2-1, fig. 7

1860 *Crania hamiltoniae* Hall, p. 77, figs. 4-5.

1867 *Crania hamiltoniae*; Hall, p. 27-28, pl. 3, figs. 17-23.

1892a *Craniella hamiltoniae*; Hall & Clarke, p. 148, 153, pl. 41, figs. 3-16.

1901 *Craniella hamiltoniae*; Kindle, p. 582-583, pl. 3, fig. 5.

1902 *Craniella hamiltoniae*; Shimer & Grabau, p. 153.

1911 *Craniella hamiltoniae*; Cleland, p. 86, pl. 12, figs. 7-8.

1913 *Craniella hamiltoniae*; Prosser & Kindle, p. 131, pl. 9, figs. 1-7.

1913 *Craniella hamiltoniae*; Clarke & Swartz, p. 549-550.

1915 *Craniella hamiltoniae*; Stauffer, P. 121.

1927 *Craniella hamiltoniae*; Stewart, p. 35, pl. 3, fig. 8.

1958 *Petrocrania hamiltoniae*; Stumm & Wright, p. 91, 105.

1965 *Petrocrania* cf. *P. hamiltoniae* Griesemer, p. 254, pl. 1, fig. 18.

1965 *Petrocrania hamiltoniae*; Rowell, p. 290-291, fig. 181. 7.

1969 *Petrocrania hamiltoniae*; Hoare & Steller, p. 270, pl. 2, figs. 13-15.

Types. Hall's (1860) original description included specimens collected from shales of the Hamilton Group in western New York, Maryland, and Virginia (exact localities unspecified), but the author did not designate a holotype. Original types cannot be traced from the previous references.

Description. Shell medium, subcircular; surface of shell marked by fine concentric growth lines.

Ventral valve cemented, marked by four impressions of the adductor muscles; two smaller central muscle scars separated by a short subcentral septum and two larger posterior scars.

Dorsal valve unknown.

Material. Total 3 complete ventral valves.

Occurrence. Coral unit, Hungry Hollow Member, Widder Formation; Arkona-Thedford-Ipperwash area, southwestern Ontario.

Discussion. Petrocrania hamiltoniae (Hall, 1860) is distinguishable from *P. inflata* Cooper and *P. leoni* (Hall) by the lower degree of convexity exhibited in its dorsal valve relative to that observed in the latter species (Hoare et al., 1969, p. 270).

Remarks. This species is quite rare in the Hamilton Group strata of the Arkona-Thedford area of southwestern Ontario. However, it is the most abundant inarticulate brachiopod found in the Silica Formation of Ohio; in life, individuals of this species may have attached to corals, bryozoans or other sessile organisms (Hoare et al., 1969, p. 270).

Genus *Philhedra* Koken, 1889

Type species: *Philhedra baltica* Koken, 1889, Viruan, Kukruse horizon (Ordovician), Kohtla-Järve, Kuttjejõu, northern Estonia.

Philhedra crenistriata (Hall, 1860)

Pl. 2-1, fig. 8

1860 *Crania crenistriata* Hall, p. 78.

1867 *Crania crenistriata*; Hall, p. 28, pl. 3, 13-16.

1969 *Philhedra crenistriata*; Hoare & Steller, p. 270-271, pl. 2, figs. 16-17.

Types. Hall (1860) did not illustrate any specimens, nor did his description include a holotype designation. However, he mentioned that the original specimens were from shale beds of the Hamilton Group, Ontario County, New York. Original types cannot be traced from the previous references.

Description. shell small to medium, encrusting, subcircular in outline.

Ventral valve unknown.

Dorsal valve slightly to moderately convex; beak located almost at the center place of the shell, inclining posteriorly; surface of dorsal valve marked with numerous, coarse, rounded, raised, and radiating costellae (8-10 in number per 2 mm), extending from the beak to the edge of the dorsal valve, interrupted by fine concentric growth lines.

Dorsal interior unknown.

Material. Total 5 complete dorsal valves.

Occurrence. Coral Unit, Hungry Hollow Member, Widder Formation; Arkona-Thedford-Ipperwash area, southwestern Ontario.

Discussion. Philhedra crenistriata (Hall, 1860) co-occurs with *P. stewarti* Fenton & Fenton, 1924 (Hoare et al., 1969, p. 271, Pl. 2, figs. 8-9) and *P. sheldoni* (White, 1862) (Hoare et al., 1969, p. 271, Pl. 2, figs. 10-12) in Unit 7 of the Silica Formation of Ohio. *P. crenistriata* is, however, readily distinguished from the latter two species by the coarser nature of its costellae and the prolongation of costellae from the beak to the edge of valves.

Order STROPHOMENIDA Öpik, 1934

Superfamily STROPHOMENOIDEA King, 1846

Family DOUVILLINIDAE Caster, 1939

Subfamily DOUVILLININAE Caster, 1939

Genus *Douvillina* Oehlert, 1887b

Type species: *Orthis dutertrii* Murchison, 1840, Ferque Quarry, exact horizon unknown (Devonian), Bas-Boulonnais, France.

Douvillina cf. *inaequistriata* (Conrad, 1842)

Pl. 2-2, figs. 6-10

Types. The original specimen of *Douvillina inaequistriata* figured by Conrad (1842) is cited as having been collected from Upper Silurian (?) shales of Moscow, Livingston County, New York. Conrad's (1842) original description did not include a holotype designation. Original types cannot be traced from the previous references.

Description. Shell medium to large, transversely sublliptical, moderately to strongly concavo-convex; unequally parvicostellate; hinge line denticulate, straight; cardinal extremities acute; maximium width along hinge line.

Ventral valve moderately to strongly convex; umbonal region flattened; ventral sulcus ill-defined; ventral interarea low; pseudodeltidium present.

Ventral interior unknown.

Dorsal valve moderately to strongly concave; fold inconspicuous. Dorsal interior unknown.

Material. Total 7 complete specimens and 3 incomplete specimens.

Occurrence. Coral Unit, Hungry Hollow Member, Widder Formation; Arkona-Thedford-Ipperwash area, southwestern Ontario.

Discussion. *Douvillina* cf. *inaequistriata* (Conrad, 1842) is distinguishable from *D. inaequistriata* (Conrad, 1842) by its more transversely extended shape and smaller number of costellae visible on shell exterior. *D. distans* Imbrie, 1959 from the Four Mile Dam Formation of the Middle Devonian Traverse Group of Michigan (Imbrie, 1959, p. 389-390, pl. 58, figs. 17-20) differs from *D.* cf. *inaequistriata* in having less acute cardinal extremities and a more strongly convex ventral valve with the greatest convexity at the umbo.

Family LEPTOSTROPHIIDAE Caster, 1939

Genus *Protoleptostrophia* Caster, 1939

Type species: *Strophomena blainvillei* Billings, 1874, Gaspé Formation (Devonian), Gaspé, Quebec.

Protoleptostrophia perplana (Conrad, 1842)

Pl. 2-3, figs. 6-11

1842 *Strophomena perplana* Conrad, p. 257, pl. 14, fig. 11.

1842 *Strophomena delthyris* Conrad, p. 258, pl. 14, fig. 19.

1842 *Strophomena pluristriata* Conrad, p. 259.

1857 *Strophomena* (*Strophodonta*) *crenistria* Hall, p. 111.

1857 *Strophomena* (*Strophodonta*) *fragilis* Hall, p. 143.

1858 *Strophodonta fragilis* Hall, p. 496, pl. 3, fig. 6.

1858 *Strophomena perplana*; Rogers, p. 827, fig. 665.

1867 *Strophodonta perplana* Hall, p. 92, 98, pl. 11, fig. 22; pl. 12, figs. 13-15; pl. 17, fig. 1.

1883 *Strophodonta perplana*; Hall, pl. 46, figs. 2-15.

1884 *Strophodonta perplana*; Walcott, p. 120, pl. 13, fig. 11.

1889 *Strophodonta perplana*; Nettelroth, p. 147, pl. 18, fig. 17.

1891 *Strophodonta perplana*; Beecher, p. 357, pl. 17, fig. 17.

1891 *Strophodonta perplana*; Whiteaves, p. 220.

1892b *Stropheodonta* (*Leptostrophia*) *perplana* Hall and Clarke, p. 288, pl. 15, figs. 2-13.

1911 *Stropheodonta perplana*; Cleland, p. 89, pl. 18, figs. 1-4.

1927 *Stropheodonta* (*Leptostrophia*) *perplana*; Stewart, p. 36, pl. 3, fig. 11.

1958 *Protoleptostrophia perplana*; Stumm & Wright, p. 107, 121, 116, 121.

1963 *Protoleptostrophia perplana*; Wright & Wright, p. 121.

Types. The original specimen figured by Conrad (1842) was from the Middle Devonian Onondaga Limestone, Schoharie, New York. Conrad's (1842) original description did not include a holotype designation. Original types cannot be traced from the previous references.

Description. Shell large, slightly concavo-convex; subquadrate in outline; surface of shell marked by numerous, closely spaced, and fine costellae, crossed by sparse lamellose growth lines, growth lines more numerous toward the anterior area; hinge line long, less than the maximum width; cardinal extremities slightly alate.

Ventral valve weakly convex, ventral interarea low (1.4-1.6 mm high), apsacline; horizontal fine growth lines present within interarea; delthyrium small; anterior commissure uniplicate.

Radial ridges absent in ventral muscle field on interior surface of ventral valve; median septum thin, shorter than half of total valve length.

Dorsal valve slightly concave; dorsal interarea linear.

Dorsal interior with small, bilobed cardinal process; dorsal muscle field small, median septum short, relatively thick; side ridges short.

Material. Total 28 incomplete specimens and 3 incomplete ventral valves.

Occurrence. Widder Formation; Ipperwash Limestone; Arkona-Thedford-Ipperwash area, southwestern Ontario.

Discussion. Protoleptostrophia perplana (Conrad, 1842) is distinguishable from *P. lirella* Imbrie, 1959 (Imbrie, 1959, p. 387-388, pl. 60, figs. 12-21) from the Middle Devonian Traverse Group of Michigan by its lower degree of convexity, finer closely-spaced costellae, and weaker and shorter ventral median septum. *P. serrata* Griesemer, 1965 from the Middle Devonian rocks of southeastern Wisconsin (Griesemer, 1965, p. 260-261, pl. 2, figs. 16-19) differs from *P. perplana* in its smaller size, smaller length/width ratio, and greater prominence of its secondary growth lines.

Family STROPHODONTIDAE Caster, 1939

Genus *Strophodonta* Hall, 1850

Type species: *Strophomena demissa* Conrad, 1842, Shore of Lake Erie (exact locality and horizon unknown, Devonian), Erie County, New York, U.S.A..

Strophodonta (*Strophodonta*) *demissa* (Conrad, 1842)

Pl. 2-4, figs. 1-16; Table 2-1; Fig. 2-1

1842 *Strophomena demissa* Conrad, p. 258, pl. 14, fig. 14.

1852 *Strophodonta dimosa* (?) Owen, tab. 3A, fig. 14.

1857 *Strophomena* (*Strophodonta*) *demissa* Hall, p. 137, fig. 1.

1857 *Strophomena* (*Strophodonta*) *subdemissa* Hall, p. 145.

1858 *Strophomena demissa*; Conrad, p. 827, fig. 666.

1858 *Strophodonta demissa* Hall, p. 495, pl. 3, fig. 5.

1867 *Strophodonta demissa*; Hall, p. 81, pl. 11, figs. 14-17; pl. 12, figs. 1-5.

1868 *Strophomena* (*Strophodonta*) *demissa*; Meek, p. 87, figs. 6a-6c.

1868 *Strophomena* (*Strophodonta*) *subdemissa*; Meek, p. 88, pl. 13, fig. 7.

1883 *Strophodonta demissa*; Hall, pl. 45, figs. 7-12.

1884 *Strophodonta demissa*; Walcott, p. 118, pl. 2, fig. 9.

1889 *Strophodonta demissa*; Nettelroth, p. 143, pl. 18, figs. 10-16; pl. 33, fig. 22.

1891 *Strophodonta demissa*; Whiteaves, p. 219.

1892b *Stropheodonta demissa*; Hall and Clarke, pl. 14, figs. 7-12.

1944 *Stropheodonta demissa*; Shimer & Shrock, p. 339, pl. 131, figs. 12-14.

1958 *Stropheodonta demissa*; Stumm & Wright, p. 93, 108, 116, 121.

1961 *Strophodonta "demissa"*; Wright & Wright, p. 294.

1963 *Strophodonta "demissa"*; Wright & Wright, p. 123.

2000 *Strophodonta* (*Strophodonta*) *demissa* (Conrad); Cocks & Rong (eds.), p. 292, fig. 186. 2a-e.

Types. The original specimen figured by Conrad (1842) was from Devonian shales exposed on the southern shore of Lake Erie, Erie County, New York. Conrad's (1842) original description did not include a holotype. The illustrations of this species occurred in the revised brachiopod treatise: One complete shell (conjoined valves) (Cocks & Rong, 2000, P. 293, figs.186. 2a-c) is from the Arkona Shale Formation, Hamilton Group, Ontario, Canada. The second ventral valve sample (figs. 186. 2d) is from the Hamilton Group, Sylvania, Ohio. The third dorsal valve sample (figs. 186. 2e) is from upper beds of the Ferron Point Formation, Middle Devonian Traverse Group, Alpena County, Michigan, U.S.A..

Description. Shell large, weakly to strongly concavo-convex; shell covered with rounded costellae (at the mid-length of shell, 2-4 in number per 2 mm), increasing by intercalation or bifurcated at or between the sparse, slightly lamellose growth lines; hinge line long, straight and denticulate.

Ventral valve weakly to strongly convex; sulcus inconspicuous; ventral interarea low (1.2 ~ 2.6 mm), apsacline; beak small, slightly incurved.

Ventral interior with two diductor scars, subelliptical to suboval; two smaller suboval adductors present at posteromedian portion of the two diductor scars, divided by a low median septum; ventral muscle field occupying half of valve length and half to three fifths of valve width.

Dorsal valve weakly to strongly concave, dorsal interarea low to linear.

Dorsal interior with strong, bilobed cardinal process; socket ridges present; two pairs of adductor scars present, lateral pair larger than medial pair, central median septum short, less than half length; side ridges short; subperipheral rim obvious; dorsal muscle field elevated, occupying about one third of the width and one half of the length of the shell.

Material. Total 75 complete specimens, 16 incomplete specimens, and 3 complete dorsal valves.

Occurrence. Arkona Shale Formation; Widder Formation; Ipperwash Limestone (unnamed formation); Arkona-Thedford-Ipperwash area, southwestern Ontario.

Discussion. *Strophodonta* cf. S. *costata* Owen, 1852 from the Middle Devonian rocks of southeastern Wisconsin (Griesemer, 1965, p. 261, pl. 2, fig. 20) is distinguished from *S.* (*Strophodonta*) *demissa* (Conrad, 1842) by its smaller size, smaller length/width ratio, and coarser, prominent and less numerous costellae. *S. halli* Cleland, 1911 from the Middle Devonian rocks of southeastern Wisconsin (Griesemer, 1965, p. 262, pl. 2, figs. 21-25) differs from *S.* (*Strophodonta*) *demissa* in its rounded to subangular, more numerous costellae (2-3 in number per mm), smaller length/width, and thickness/length ratios (0.73 amd 0.26 respectively). *S. alpenensis* Grabau, 1913 from the Norway Point Formation of the Middle Devonian Traverse Group of Michigan (Imbrie, 1959, p. 382, pl. 57, figs. 7-11) is distinguishable from *S.* (*Strophodonta*) *demissa* by its subquadrate

	W	L	T	W_1	L/W	T/W	W_1/W
MEAN	31.89	27.90	11.52	27.97	0.88	0.36	0.88
STD	4.80	3.99	2.04	4.34	0.05	0.03	0.04
MIN	21.07	17.58	7.19	18.95	0.81	0.30	0.79
MAX	40.04	36.47	15.95	36.00	0.96	0.44	0.94
N	36	36	36	36	36	36	36

Table 2-1. Statistical data of shell dimensions (mm) for complete specimens of *Strophodonta* (*Strophodonta*) *demissa* (Conrad, 1842), sample from Collecting locality 5, Coral Unit, Hungry Hollow Member, Widder Formation.

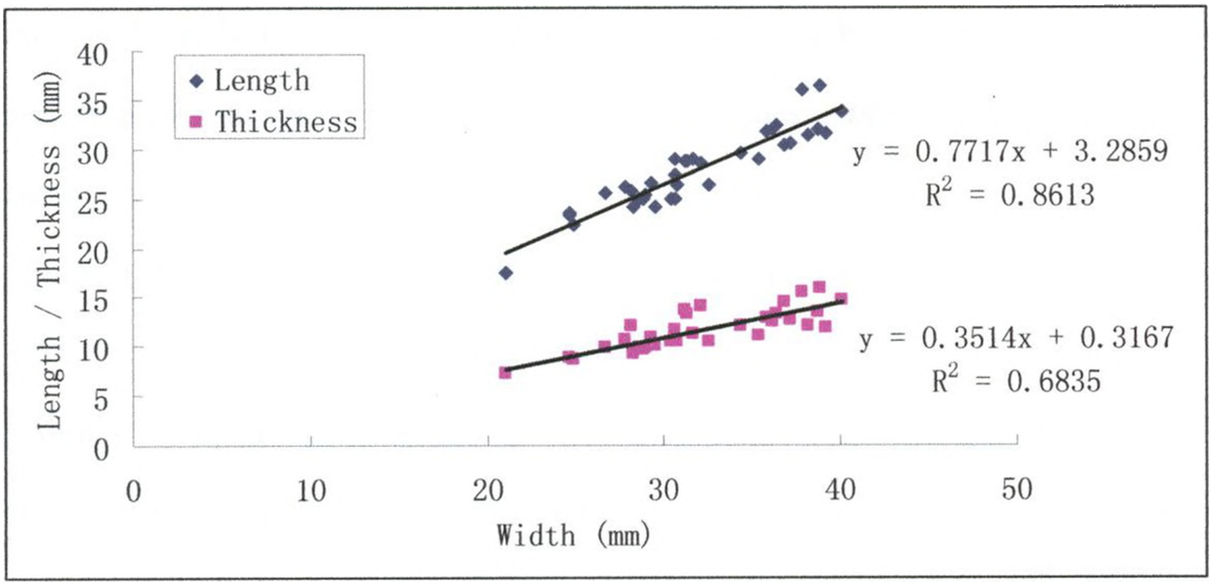


Fig. 2-1. Length-width and thickness-width graphs for complete specimens of *Strophodonta* (*Strophodonta*) *demissa* (Conrad, 1842), sample from Collecting locality 5, Coral Unit, Hungry Hollow Member, Widder Formation.

outline and subangular to subrounded costellae which are nearly uniform in size.

Strophodonta extenuata ferronensis Imbrie, 1955

Pl. 2-5, figs. 1-5; Pl. 2-6, figs. 6-7; Table 2-2; Fig. 2-2

1955 *Strophodonta extenuata ferronensis* Imbrie, p. 6, figs. 1-5.

1961 *Strophodonta extenuata ferronensis* Imbrie; Stumm, p. 153.

1969 *Strophodonta extenuata ferronensis* Imbrie; Driscoll & Mitchell, p. 121.

Types. Holotype USNM 124333, upper Ferron Point Formation (Middle Devonian), Traverse Group, abandoned shale pit, Alpena Portland Cement Co., Alpena County, Michigan.

Description. Shell large, moderately concavo-convex, outline transversely subelliptical to subquadrate; exterior surface covered with numerous, fine and rounded costellae (at mid-length of shell, 4-5 in number per 2 mm), increasing by intercalation; surface of shell marked with sparse slightly lamellose growth lines; hinge line long, straight and denticulate.

Ventral valve moderately convex; sulcus inconspicuous; ventral interarea low (1.5-3.0 mm), apsacline; beak small, slightly incurved.

Ventral valve interior with two suboval diductor scars, two smaller elongate oval adductors poteromedial to diductor scars; median septum long and thick; ventral muscle field occupying about two thirds of valve length and three fifths of valve width.

Dorsal valve moderately concave; dorsal interarea low, hypercline.

Dorsal interior with strong, bilobed cardinal process; two pairs of adductor scars present, lateral pair slightly larger than median pair, central median septum relatively long and thin; subperipheral rim obvious; dorsal muscle field occupying about one third of valve width and one half of valve length; dorsal muscle field elevated on platform.

Material. Total 85 complete specimens, 23 incomplete specimens, 1 dorsal valve, and 1 ventral valve.

Occurrence. Arkona Shale Formation; Arkona-Thedford-Ipperwash area, southwestern Ontario.

Discussion. Strophodonta extenuata ferronensis Imbrie, 1955 differs from *S.* (*Strophodonta*) *demissa* (Conrad, 1842) in its finer and denser costellae, lower degree of convexity at umbonal region, different area proportion and shape of muscle fields. Although the pattern of the ornamentation of *S. extenuata genshawensis* Imbrie, 1959 from the Genshaw Formation of the Middle Devonian Traverse Group of Michigan (Imbrie, 1959, p. 378-379, pl. 54, figs. 23-27) is similar to that of *S. extenuata ferronensis*, the former differs from the latter in its smaller length/width ratio and tapering lateral margins.

Strophodonta cf. *fascis* Imbrie, 1959

Pl. 2-5, fgis. 6-10; Pl. 2-6, figs. 1-5; Fig. 2-3

Types. Holotype of *Strophodonta fascis* Imbrie, 1959, USNM 124330, from shales of the lower Ferron Point Formation (Middle Devonian), Traverse Group, Quarry of Kelly

	W	L	T	W_1	L/W	T/W	W_1/W
MEAN	30.08	24.81	8.14	25.34	0.82	0.27	0.88
STD	5.67	5.53	2.29	5.75	0.06	0.04	0.05
MIN	18.81	13.90	3.65	13.79	0.72	0.19	0.77
MAX	40.21	33.66	12.58	35.78	0.90	0.35	0.97
N	25	25	25	25	25	25	25

Table 2-2. Statistical data of shell dimensions (mm) for complete specimens of *Strophodonta extenuata ferronensis* Imbrie, 1955, sample from Collecting locality 2, Arkona Shale Formation.

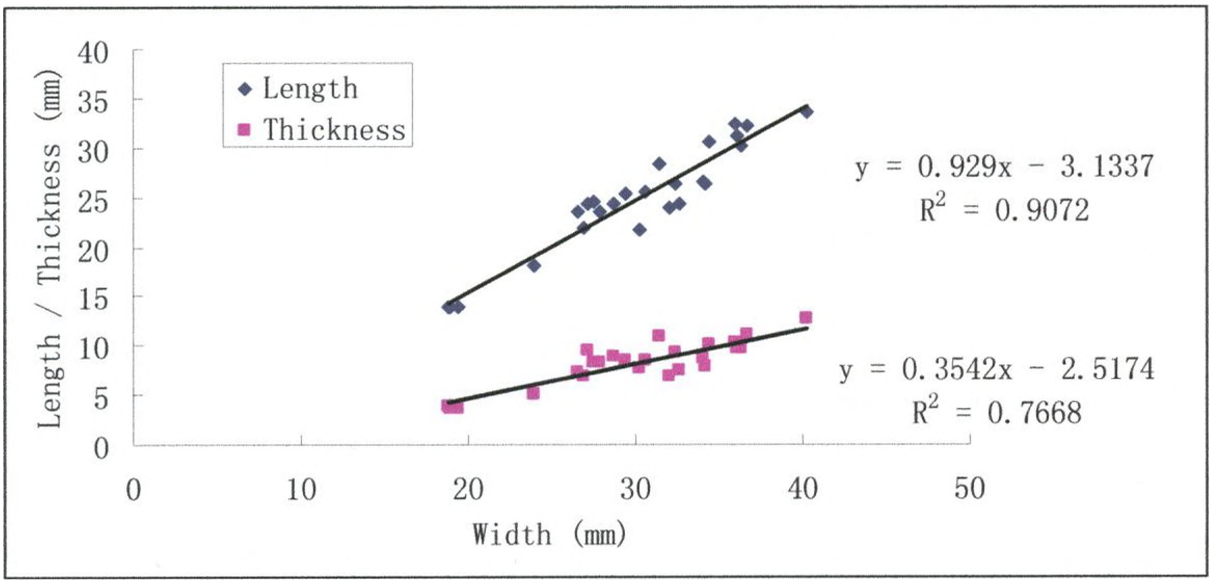


Fig. 2-2. Length-width and thickness-width graphs for complete specimens of *Strophodonta extenuata ferronensis* Imbrie, 1955, sample from Collecting locality 2, Arkona Shale Formation.

Island Lime and Transport Co., Rockport, Alpena County, Michigan.

Description. Shell large, moderately concavo-convex, outline subquadrate; maximum width near mid-length; shell covered with numerous, fine and rounded costellae (2-3 in number per 2 mm at mid-length of shell), increasing by intercalation; anteriorly, costellae decrease in size; surface of shell marked with sparse slightly lamellose growth lines; hinge line long, straight and denticulate.

Ventral valve moderately and evenly convex; sulcus inconspicuous; ventral interarea relatively high (3.0 ~ 3.2 mm), apsacline; beak small, slightly incurved.

Ventral valve interior with muscle field.

Dorsal valve gently and evenly concave; dorsal interarea low, hypercline.

Dorsal interior with strong, bilobed cardinal process; pseudopunctae present; dorsal muscle field elevated on platform (Figure 2-3).

Material. Total 7 incomplete specimens.

Occurrence. Arkona Shale Formation; Arkona-Thedford-Ipperwash area, southwestern Ontario.

Discussion. Strophodonta cf. *fascis* Imbrie, 1959 is similar in overall shape to *S. fascis* Imbrie, 1959 (Imbrie, 1959, p. 379, pl. 53, figs. 30-35), except that the umbonal region of the ventral valve is not as swollen as in the latter. Since the internal characters of *S. fascis* are also unknown, the total seven incomplete specimens are tentatively assigned to *S.* cf. *fascis*. The identification at species level requires further study with a greater number of specimens. *S. paula* Imbrie, 1959 from the Four Mile Dam Formation of the Middle Devonian Traverse Group of Michigan (Imbrie, 1959, p. 380, pl. 56, figs. 23-26) resembles *S.* cf. *fascis* in its subquadrate outline. However, *S. paula* differs by having a

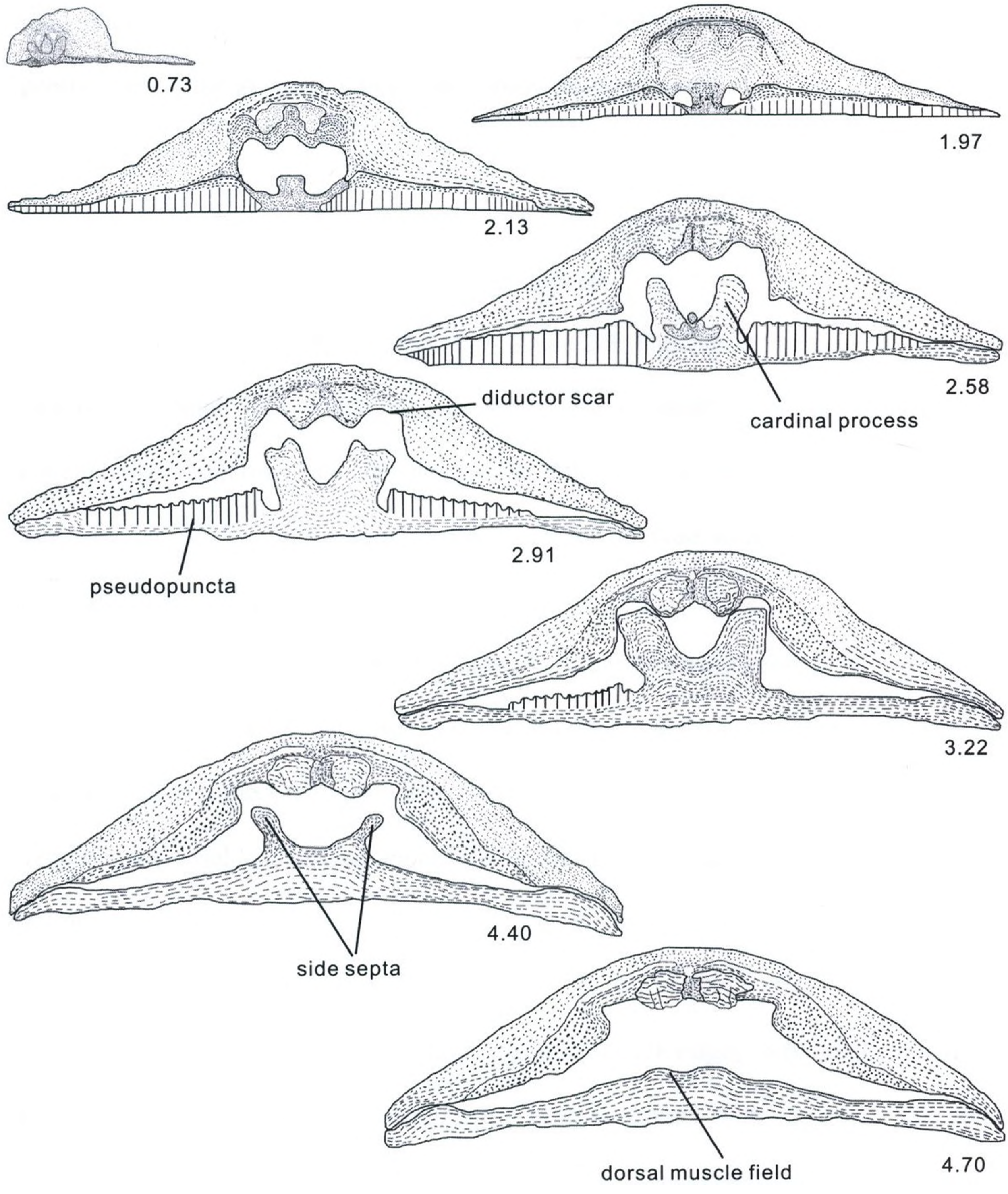


Fig. 2-3. Selected transverse serial sections of *Strophodonta* cf. *fascis* Imbrie, 1959. UMMP 74040. Arkona Shale. Lot 8, Arkona, Ontario. Distances in mm from posterior tip of ventral umbo. X4.0

moderately convex ventral valve with a somewhat flattened middle portion and a more gently convex dorsal valve with flattened posterolateral areas.

Strophodonta sp.

Pl. 2-6, figs. 8-9 ; Table 2-3; Fig. 2-4

Description. Shell thin, medium-sized, sub-planar to slightly concavo-convex; shell covered with numerous fine costellae (at the mid-length of shell, 8-9 in number per 2 mm), increasing by intercalation; surface of shell marked with sparse growth lines; hinge line long, straight and denticulate.

Ventral valve slightly to moderately convex; sulcus inconspicuous.

Ventral valve interior with two suboval diductor scars, two smaller elongate oval adductors posteromedial to diductor scars; adductors separated by a median septum; ventral muscle field occupying about three fifths of valve length and two fifths of valve width.

Dorsal valve flat to slightly concave.

Dorsal interior with bilobed cardinal process; socket ridges very small, divergent; two pairs of adductor scars present, central median septum faint and short; side septa short; dorsal muscle field and subperipheral rim poorly developed.

Material. Total 7 complete ventral valves and 7 complete dorsal valves.

Occurrence. Hungry Hollow Member, Widder Formation; Arkona-Thedford-Ipperwash area, southwestern Ontario.

Discussion. The shells of *Strophodonta* sp. are much thinner, smaller, more weakly convex, and have more densely costellae than other congeneric species. Although *S. discus* Imbrie, 1959 from the Alpena Limestone of the Middle Devonian Traverse Group of Michigan (Imbrie, 1959, p. 382, pl. 58, figs. 7-11) also has a subplanar to very gentle concavo-convex lateral profile, it is distinguishable from *S.* sp. (Table 2-3) in having a larger size (measurements of the holotype: length: 21 mm; width: 25 mm; thickness: 3 mm), a subquadrate outline, and stronger, broader, subangular costellae (numbering 10 per 10 mm at the mid-length of shell).

Strophodonta titan titan Imbrie, 1959 ?

Pl. 2-7, figs. 16-17

1959 *Strophodonta titan titan* Imbrie, p. 379-380, pl. 55, figs. 1-6.

Types. Holotype USNM 124267, Gravel Point Formation (Middle Devonian), Traverse Group, Quarry of Petoskey Portland Cement Co., Emmet County, northern Michigan.

Description. Shell very large for the genus, subsemicircular, moderately to strongly concavo-convex.

Ventral valve moderately to strongly convex; valve covered with numerous, coarse and elevated costellae (at the mid-length of shell, 4-5 in number per 5 mm), costellae angular, subequal, either relatively constant in size or becoming finer anteriorly.

Ventral interior unknown.

Dorsal valve unknown.

Material. Total 3 incomplete ventral valves.

Occurrence. Coral Unit, Hungry Hollow Member, Widder Formation; Arkona-

	W	L	T	L/W	T/W
MEAN	13.21	9.12	1.79	0.69	0.13
STD	3.01	2.51	0.46	0.06	0.01
MIN	9.35	6.49	1.23	0.61	0.12
MAX	17.52	12.95	2.46	0.75	0.15
N	6	6	6	6	6

Table 2-3. Statistical data of shell dimensions (mm) for ventral valves of *Strophodonta* sp., sample from Collecting locality 4, Coral Unit, Hungry Hollow Member, Widder Formation.

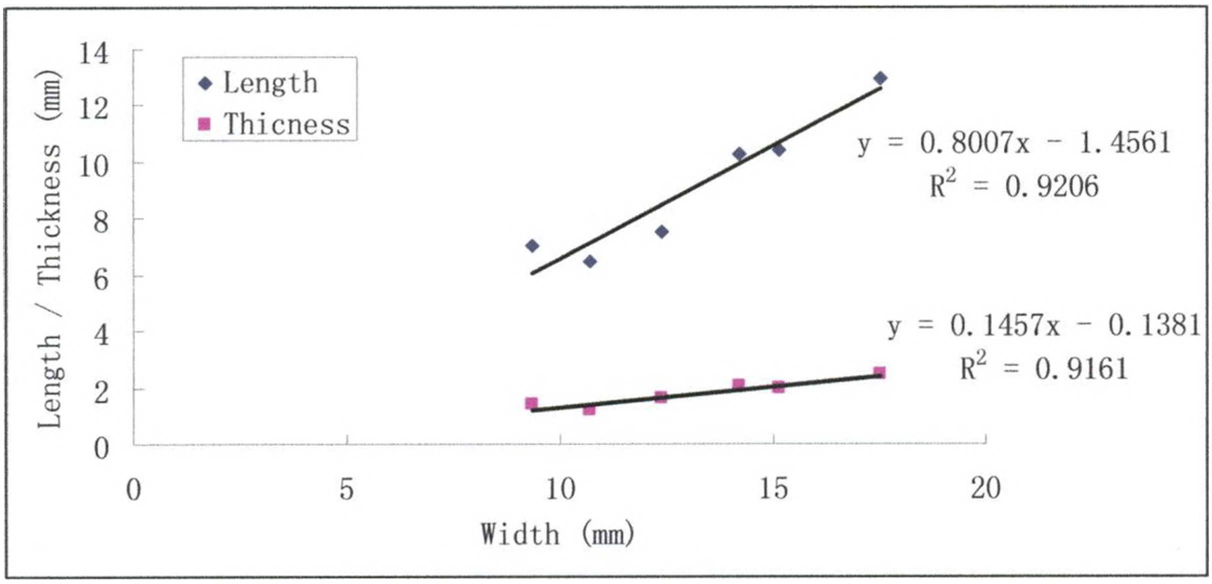


Fig. 2-4. Length-width and thickness-width graphs for ventral valves of *Strophodonta* sp., sample from Collecting locality 4, Coral Unit, Hungry Hollow Member, Widder Formation.

Thedford-Ipperwash area, southwestern Ontario.

Discussion. According to the visible exterior features, these three incomplete ventral valves are similar to the holotype. However, since these three incomplete ventral valves are not complete and their interior features are unknown, they cannot be unequivocally assigned to *S. titan titan* Imbrie, 1959. The three ventral valves examined are distinguishable from *S. titan costella* Imbrie, 1959 (Imbrie, 1959, p. 379, pl. 55, figs. 14-18) by its larger size, and coarser, less numerous costellae.

Genus *Megastrophia* Caster, 1939

Type species: *Stropheodonta concava* Hall, 1857, Seneca Lake (exact locality and horizon unknown, probably Middle Devonian), Moscow, U.S.A..

Megastrophia concava (Hall, 1857)

Pl. 2-3, figs. 1-5

1857 *Strophomena* (*Strophodonta*) *concava* Hall, p. 115, 140, fig. 1.

1857 *Strophodonta concava* Hall, p. 115.

1867 *Strophodonta concava*; Hall, p. 96, pl. 16, figs. 1a-1h.

1889 *Strophodonta concava*; Whiteaves, p. 123.

1902 *Stropheodonta concava*; Shimer & Grabau, p. 182.

1915 *Stropheodonta concava* (?); Stauffer, p. 50.

1944 *Megastrophia concava*; Shimer & Shrock, p. 339, pl. 130, fig. 25; pl. 131, figs. 1-4.

1958 *Megastrophia concava*; Stumm & Wright, p. 106, 115.

1959 *Megastrophia concava*; Imbrie, p. 388, pl. 59, figs. 10-13.

1961 *Megastrophia concava*; Stumm, p. 157.

1961 *Megastrophia concava*; Wright & Wright, p. 294.

1963 *Megastrophia concava*; Wright & Wright, p. 123.

Types. The specimen illustrated by Hall (1867, Pl. 16, fig. 1b, c) was designated as lectotype by Imbrie (1959). Although the exact locality and horizon from which the lectotype was collected are unknown, Hall (1867) mentioned that this species is very common in the soft shales of the Hamilton Group from Cayuga Lake westward to Lake Erie.

Description. Shell large, strongly concavo-convex or subhemispherical; shell marked by numerous elevated costellae (2-4 in number per 2 mm at the mid-length of shell), increasing by intercalation, parvicostellae unequal, all costellae crossed by fine concentric growth lines; hinge line long, straight and denticulate.

Ventral valve moderately to strongly convex; surface marked by an irregular middle fold or ridge in some specimens; ventral interarea low (1.6 ~ 2.5 mm), apsacline; beak small, incurved.

Ventral valve interior with two suboval diductor scars, two smaller elongate oval adductors located posteromedially to diductor scars; adductors scars divided by low median septum; muscle bounding ridges absent; ventral muscle field slightly transverse, occupying about half of valve length and one third of valve width.

Dorsal valve moderately to strongly concave; dorsal interarea low, anacline.

Dorsal valve interior with bilobed cardinal process, u-shaped, joined at their base, projecting to hinge line; socket ridges small, thin, divergent; two pairs of adductor scars present, lateral pair larger than medial pair; central median septum short, less than half length; side ridges short; subperipheral rim obvious; dorsal muscle field elevated, occupying about one third of valve width and two fifths of valve length.

Material. Total 24 incomplete specimens.

Occurrence. Widder Formation; Ipperwash Limestone; Arkona-Thedford-Ipperwash area, southwestern Ontario.

Discussion. Megastrophia (M.) proxicostellata Fagerstrom, 1961 from the Middle Devonian Formosa Reef Limestone of southwestern Ontario (Fagerstrom, 1961, p. 19-20, pl. 8, figs. 4-8) differs from *M. concava* (Hall, 1857) in its smaller size and different ornamentation of the shell exterior. The shell surface of *M. (M.) proxicostellata* is covered by evenly spaced, uniform costae and numerous finer costellae, which are different from the numerous elevated costellae increasing by intercalation and unequal parvicostellae on the surface of *M. concava*. *M. gibbosa* Imbrie, 1959 from the Four Mile Dam Formation of the Middle Devonian Traverse Group of Michigan (Imbrie, 1959, p. 388-389, pl. 59, figs. 1-7) differs from *M. concava* in its smaller size, more strongly concavo-convex outline, and more swollen ventral umbonal region. Although *M. hemispherica* (Hall, 1857) from the Lower Devonian rocks of New York State (Boucot, 1959b, p. 751-752, pl. 95, figs. 5-8) is similar to *M. concava*, it is distinguishable from the latter in having a more convex ventral valve and nearly uniform costellae.

Genus *Pholidostrophia* Hall & Clarke, 1892b

Type species: *Strophomena nacrea* Hall, 1857, Middle Devonian Hamilton Group (exact locality and horizon unknown), town of Darien, Genesee County, western New York.

Pholidostrophia nacrea (Hall, 1857)

Pl. 2-8, figs. 6-12; Table 2-4; Fig. 2-5

1857 *Strophomena* (*Strophodonta*) *nacrea* Hall, p. 144.

1858 *Strophomena lepida* Hall, p. 493, pl. 3, fig. 3.

1867 *Strophodonta nacrea*; Hall, p. 104, pl. 18, fig. 1.

1883 *Strophodonta nacrea*; Hall, pl. 46, figs. 20-24.

1889 *Strophodonta nacrea*; Whiteaves, p. 123.

1889 *Strophodonta nacrea*; Nettelroth, p. 146.

1892b *Stropheodonta* (*Pholidostrophia*) *nacrea* Hall & Clarke, p. 287, pl. 15, figs. 20-24.

1894b *Stropheodonta* (*Pholidostrophia*) *nacrea*; Hall & Clarke, pl. 84, fig. 11.

1897 *Pholidostrophia iowaensis* (Owen); Schuchert, p. 308.

1898 *Pholidostrophia iowensis*; Whiteaves, p. 382.

1915 *Pholidostrophia iowaensis*; Stauffer, p. 122.

1958 *Pholidostrophia nacrea*; Stumm & Wright, p. 107, 121.

1961 *Pholidostrophia nacrea*; Fagerstrom, p. 19, pl. 8, figs. 2-3.

Types. Hall's (1857) original description did not include a holotype or illustrations of specimens, but did indicate that the original specimens were from the rocks of the Hamilton Group near the town of Darien, Genesee County, New York. Original specimens cannot be traced from previous references.

Description. Shell medium to large, concavo-convex, semielliptical, transversely extended; surface of shell covered a few squamous growth lines; hinge line denticulate, slightly less than the greatest width; anterior commissure rectimarginate.

Ventral valve moderately convex; beak minute, scarcely elevated above the hinge; ventral sulcus inconspicuous; deltidium flat; foramen absent.

Ventral interior with two flabelliform diductor scars; two elongate oval adductors scars located posteromedially to diductor scars; two adductors scars divided by a low median septum.

Dorsal valve moderately concave.

Dorsal interior with bilobed cardinal process; two pairs of adductor scars present, lateral pair larger than medial pair, each pair divided by a low median septum.

Material. Total 45 complete specimens, 75 incomplete specimens, 6 incomplete dorsal valves, and 8 incomplete ventral valves.

Occurrence. Widder Formation; Arkona-Thedford-Ipperwash area, southwestern Ontario.

Discussion. Pholidostrophia nacrea (Hall, 1857) is distinguishable from *P. gracilis gracilis* Imbrie, 1955 (Imbrie, 1959, p. 386, pl. 61, figs. 1-10) from the Middle Devonian Traverse Group of Michigan by its more obviously squamous growth lines and greater degree of convexity. *p. geniculata* Imbrie, 1959 (Imbrie, 1959, p. 387, pl. 60, figs. 1-7) differs from *P. nacrea* in its less inflated umbonal region and long mucronate cardinal extremities. *P.* (*P.*) *iowensis obscura* Griesemer, 1965 (Griesemer, 1965, p. 260, pl. 2, figs. 13-15) resembles *P. nacrea* in overall shape; however, the

	W	L	T	W_1	L/W	T/W	W_1/W
MEAN	17.99	13.65	5.08	14.68	0.76	0.28	0.79
STD	2.13	1.67	1.01	1.22	0.06	0.04	0.04
MIN	13.75	10.98	3.38	12.18	0.68	0.21	0.74
MAX	21.41	17.46	7.10	15.99	0.88	0.35	0.85
N	19	19	19	15	19	19	15

Table 2-4. Statistical data of shell dimensions (mm) for complete specimens of *Pholidostrophia nacrea* (Hall, 1857), sample from Collecting locality 5, Coral Unit, Hungry Hollow Member, Widder Formation.

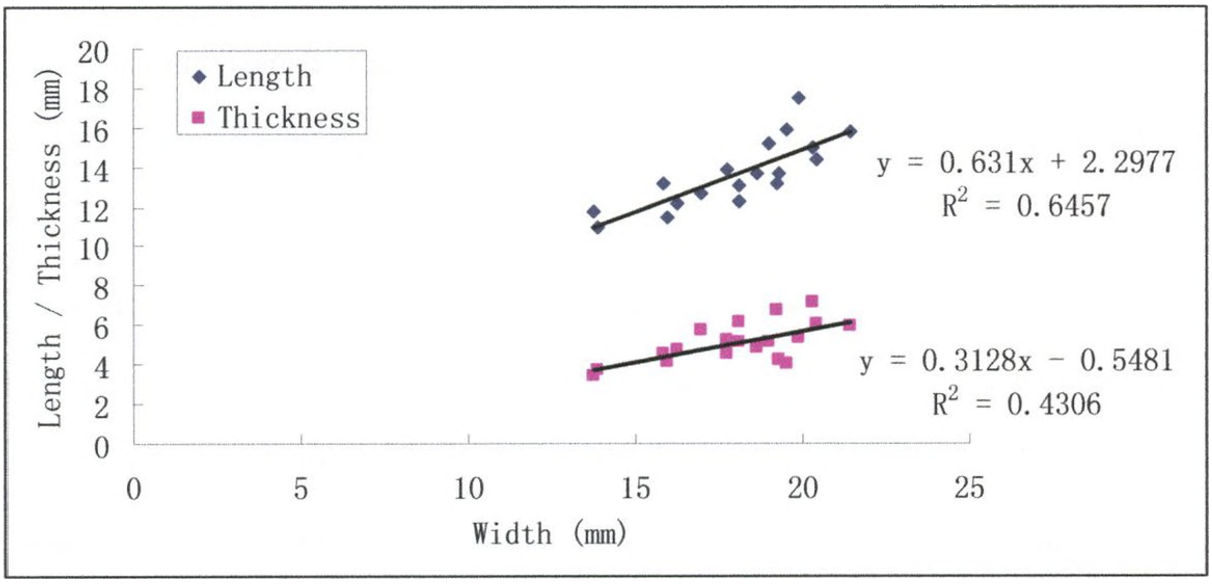


Fig. 2-5. Length-width and thickness-width graphs for complete specimens of *Pholidostrophia nacrea* (Hall, 1857), sample from Collecting locality 5, Coral Unit, Hungry Hollow Member, Widder Formation.

former subspecies differs from the latter in the weaker convexity of its ventral valve, its crescent-shaped muscle scars, and distinct radial ridges anterior to the muscle scars (Griesemer, 1965, p. 260).

Order PRODUCTIDA Sarytcheva & Sokolskaya, 1959

Suborder CHONETIDINA Muir-Wood, 1955

Superfamily CHONETOIDEA Bronn, 1862

Family CHONETIDAE Bronn, 1862

Genus *Devonochonetes* Muir-Wood, 1962

Type species: *Chonetes coronatus* Hall, 1857, Middle Devonian Hamilton Group, Cayuga Lake, western New York.

Devonochonetes arkonensis n. sp.

Pl. 2-6, figs. 10-14; Pl. 2-7, figs. 6-15; Table 2-5; Fig. 2-6; Fig. 2-7

Diagnosis. Shell small to medium, concavo-convex; length to width ratio of 0.68-0.82, width of hinge line to width of shell ratio of 0.82-0.99 (Table 2-6); costellae bifurcated or increased by intercalation.

Types. Holotype, W 2923, from the upper portion of Arkona Shale Formation, south pit, Hungry Hollow, Ontario; paratypes W 2915 and W 2917, both from the upper portion of Arkona Shale Formation, south pit, Hungry Hollow; paratype W 2916, from the Thedford Member, Widder Formation, north bank of Ausable River, Hungry Hollow, Ontario.

Etymology. Specific name refers to the Arkona Shale Formation, Arkona, where the species is dominant.

Description. Shell small to medium, transversely extended; shell surface covered with numerous, closely spaced, slender costellae (9-12 in number per 2 mm at the surface approximately 2mm anterior to the hinge line), which are bifurcated or increasing by intercalation; hinge line straight, slightly shorter than the maximum width; spines orthomorph oblique.

Ventral valve moderately convex; ventral interarea low (less than 1 mm high), apsacline; sulcus ill-defined.

Ventral interior with inner deltidial plates; dental teeth massive; median septum narrow, long, about half the shell length.

Dorsal valve moderately concave; dorsal interarea linear; external cardinal process prominent, quadrilobate.

Dorsal interior: Cardinal process bilobate posteriorly and quadrilobate to trilobate anteriorly; dental sockets shallow; muscle field elevated; median septum long, narrow, supporting cardinal process (Figure 2-6).

Material. Total 190 complete specimens and 60 incomplete specimens.

Occurrence. Arkona Shale Formation; Widder Formation; Arkona-Thedford-Ipperwash area, southwestern Ontario.

Discussion. This new species (Table 2-5, Figure 2-7) is distinguished from *Devonochonetes* sp. from the Wanakah Member of the Ludlowville Formation (Middle Devonian Hamilton Group) in Erie County of New York (Table 2-6, Figure 2-8) by its higher T/W and W_1/W ratios, and denser costellae. *Arcuaminetes scitulus* (Hall, 1857) was once assigned to genus *Devonochonetes*. The shape of *D. arkonensis* n. sp. is

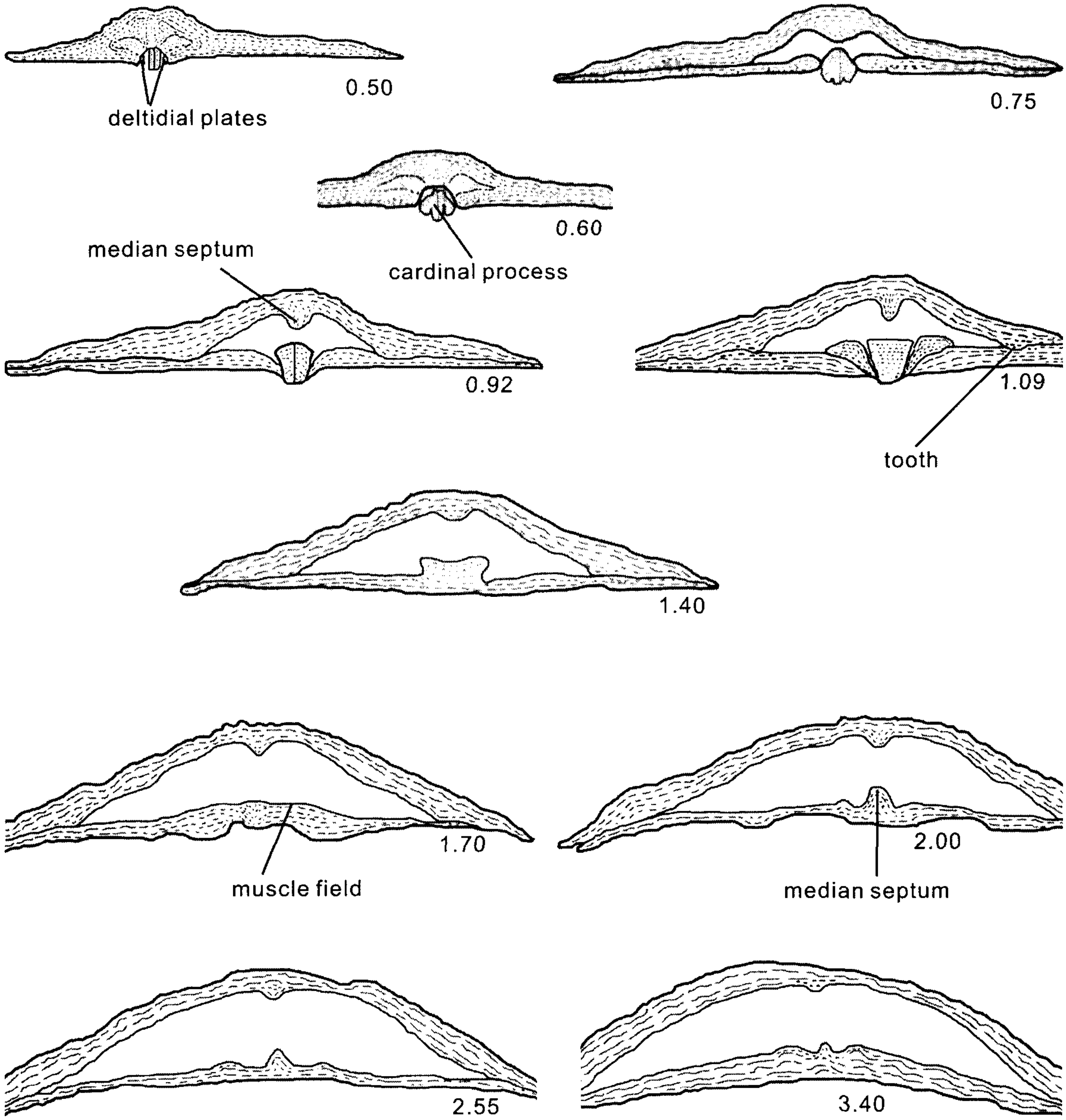


Fig. 2-6. Selected transverse serial sections of *Devonochonetes arkonensis* n. sp.. W 2915. Paratype. Arkona Shale. Collecting locality 1. Distances in mm from posterior tip of ventral umbo. X8.0

	L	W	L/W	T	W_1	W_1/W	CN
MEAN	7.11	9.78	0.73	2.07	9.09	0.90	11
STD	0.72	0.99	0.03	0.41	1.03	0.05	0.83
MIN	5.64	8.05	0.68	1.38	6.68	0.82	9
MAX	8.47	11.64	0.82	2.79	10.45	0.99	12
N	45	45	45	45	45	45	45

Table 2-5. Statistical data of shell dimensions (mm) for complete specimens of *Devonochonetes arkonensis* n. sp., sample from Collecting locality 1, Arkona Shale Formation.

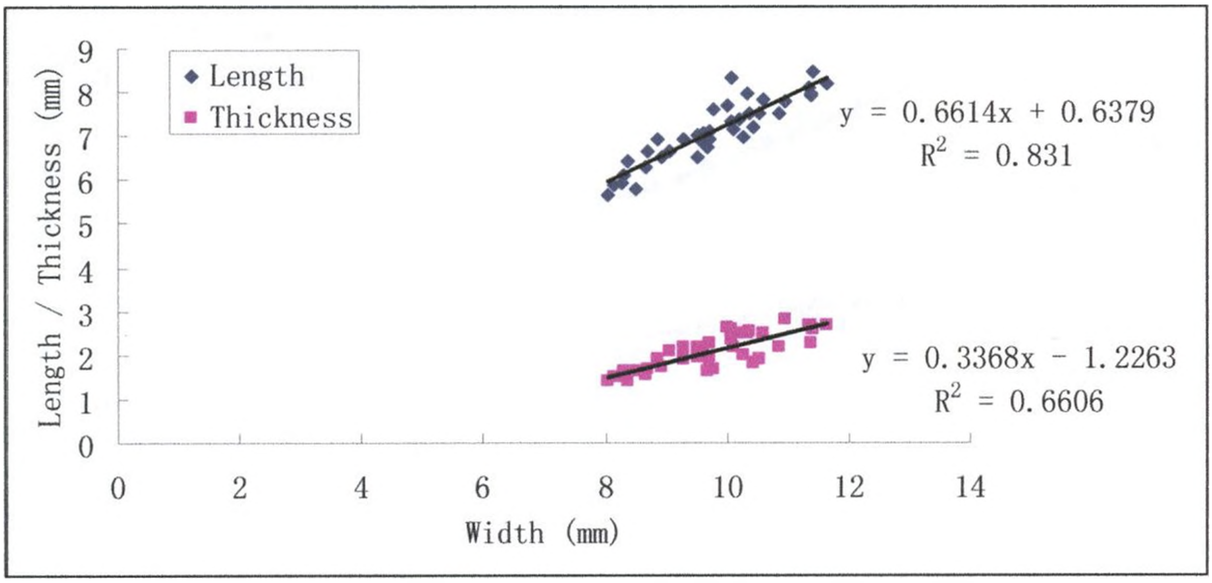


Fig. 2-7. Length-width and thickness-width graphs for complete specimens of *Devonochonetes arkonensis* n. sp., sample from Collecting locality 1, Arkona Shale Formation.

	L	W	L/W	T	W_1	W_1/W	CN
MEAN	7.87	11.28	0.70	2.61	9.22	0.83	8
STD	0.87	1.28	0.01	0.37	1.12	0.07	0.56
MIN	6.27	8.86	0.67	1.95	7.35	0.68	7
MAX	9.65	13.77	0.73	3.19	10.86	0.91	9
N	25	25	25	25	25	25	25

Table 2-6. Statistical data of shell dimensions (mm) for complete specimens of *Devonochonetes* sp., sample from Shale Pit, near Big Tree Road at Bay View, Erie County, New York, Wanakah Member, Ludlowville Formation, Hamilton Group.

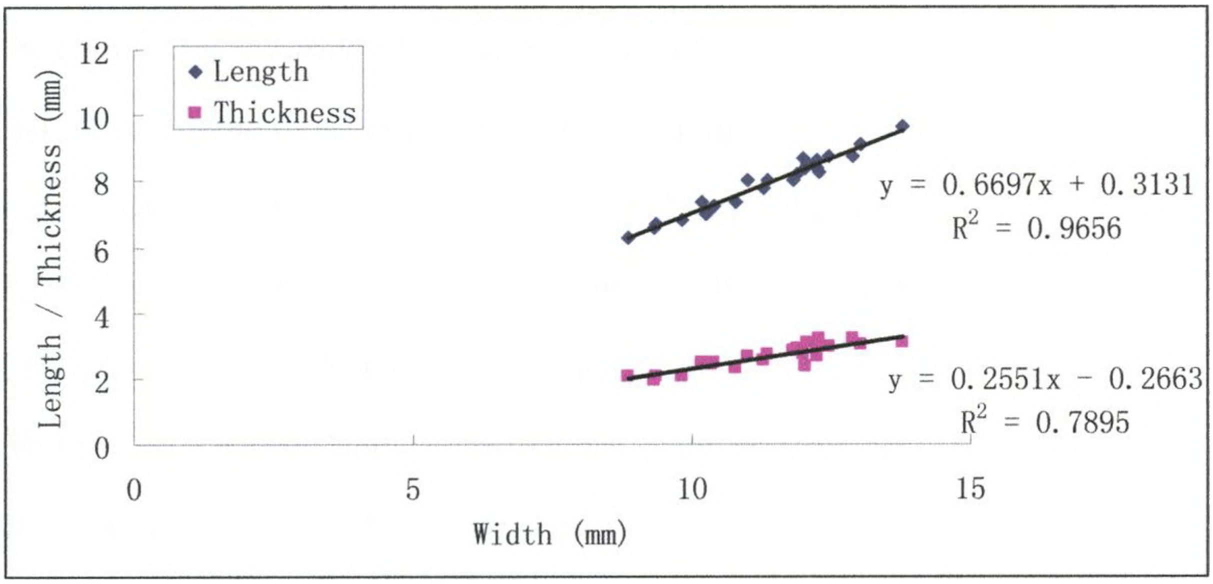


Fig. 2-8. Length-width and thickness-width graphs for complete specimens of *Devonochonetes* sp., sample from Shale Pit, near Big Tree Road at Bay View, Erie County, New York, Wanakah Member, Ludlowville Formation, Hamilton Group.

somewhat similar to that of *A. scitulus* (Hall, 1857); there are, however, notable differences in these forms. The size of *A. scitulus* (average width = 8.6 mm) is relatively smaller than *D. arkonensis* n. sp. (average width = 9.78 mm). *D. arkonensis* n. sp. has denser costellae (11 costellae per 2 mm at the place approximately 2mm anterior to the hinge line) than *A. scitulus* (10 costellae per 3 mm). In terms of interior features, the cardinal process in dorsal valve of *A. scitulus* is bilobate and a pair of well-defined anderidia is high and diverge at an angle of 70° (Bizzarro, 1995, p. 161). However, in dorsal valve of *D. arkonensis* n. sp., a pair of anderidia are clearly fused posteriorly with the cardinal process and weakly divergent anteriorly.

Devonochonetes coronatus (Conrad, 1842)

Pl. 2-7, figs. 1-5; Table 2-7; Fig. 2-9

1842 *Strophomena carinata* Conrad, p. 257, pl. 14, fig. 13.

1842 *Strophomena syrtalis* Conrad, p. 253, pl. 14, fig. 1.

1854 *Chonetes littoni* Norwood and Pratten, p. 25, pl. 2, fig. 4.

1854 *Chonetes maclurea* Norwood and Pratten, p. 28, pl. 2, fig. 8.

1854 *Chonetes taomyi* Norwood and Pratten, p. 28, pl. 2, fig. 9.

1854 *Chonetes martini* Norwood and Pratten, p. 29, pl. 2, fig. 10.

1857 *Chonetes coronata* Hall, p. 146, figs. 1-2.

1867 *Chonetes coronata* Hall, p. 133, pl. 21, figs. 9-12.

1883 *Chonetes coronata* Hall, pl. 47, figs. 10, 11, 24, 26, 33, 39, 41, 43.

1892b *Chonetes coronata*; Hall & Clarke, pl. 16, figs. 10, 11, 24, 26, 33, 39, 41, 43.

1962 *Devonochonetes coronatus*; Muir-Wood, p. 44, fig. 6A-6C; pl. 10, figs. 1-2.

Types. Conrad's (1842) original description did not include a holotype designation. However, the author noted that the figured specimen was collected from shales of the Middle Devonian Hamilton Group, Moscow, Livingston County, New York. A topotype in the United States National Museum was studied. It was from the Kashong Member, Middle Devonian Hamilton Group, Bowen Brook, New York.

Description. Shell large (average width: 21.96 mm, average length: 15.92 mm, average thickness: 3.96 mm), transverse to sub-quadrangular, concavo-convex; shell surface covered with fine costellae, bifurcated or increasing by intercalation; hinge line straight, shorter than the maximum shell width.

Ventral valve moderately convex; ventral interarea apsacline, horizontal fine growth lines present within interarea; sinus ill-defined.

Ventral interior unknown.

Dorsal valve moderately concave; dorsal interarea hypercline; chilidium present.

Dorsal interior unknown.

Material. Total 18 complete specimens and 8 incomplete specimens.

Occurrence. Arkona Shale Formation; Widder Formation; Arkona-Thedford-Ipperwash area, southwestern Ontario.

Discussion. Devonochonetes arkonensis n. sp. can be distinguished from *D. coronatus* (Hall, 1842) by its much smaller size, and the more delicate appearance of the costellae, these features being both denser and thinner in the former than the latter.

	L	W	L/W	T	W_1	W_1/W	CN
MEAN	15.92	21.96	0.72	3.96	18.16	0.82	8.30
STD	2.36	3.00	0.03	1.05	3.05	0.04	0.95
MIN	13.04	18.11	0.67	2.71	14.63	0.78	7
MAX	20.18	27.13	0.76	6.32	24.74	0.91	10
N	10	10	10	10	10	10	10

Table 2-7. Statistical data of shell dimensions (mm) for complete specimens of *Devonochonetes coronatus* (Conrad, 1842), sample from Collecting locality 2, Arkona Shale Formation.

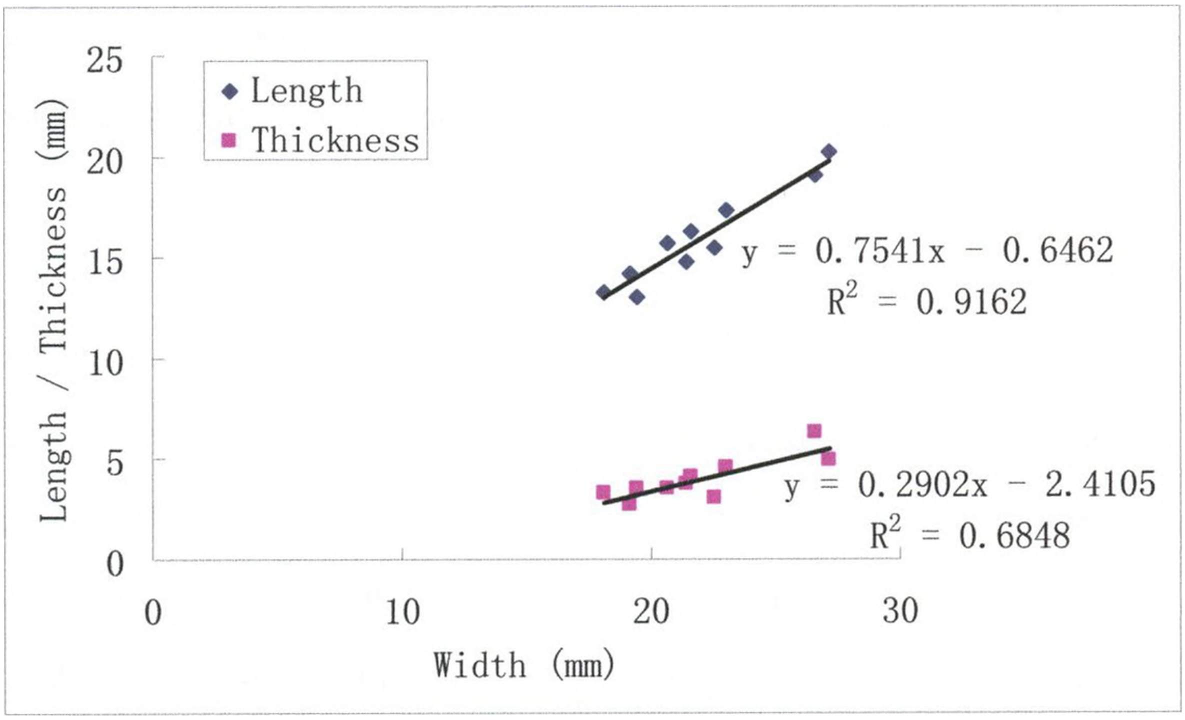


Fig. 2-9. Length-width and thickness-width graphs for complete specimens of *Devonochonetes coronatus* (Conrad, 1842), sample from Collecting locality 2, Arkona Shale Formation.

Suborder PRODUCTIDINA Waagen, 1883

Superfamily PRODUCTOIDEA Gray, 1840

Family PRODUCTELLIDAE Schuchert, 1929

Subfamily PRODUCTELLINAE Schuchert, 1929

Genus *Productella* Hall, 1867

Type species: *Productus subaculeatus* Murchison, 1840, Ferques, Bas-Boulonnais, France, Eifelian (Middle Devonian).

Productella truncata (Hall, 1857)

Pl. 2-8, figs. 13-17

1857 *Productus truncatus* Hall, p. 171.

1867 *Productella truncata* Hall, p. 160, pl. 23, figs. 12-24.

1884 *Productus* (*P.*) *truncatus* Walcott, p. 131, pl. 14, fig. 2.

1889 *Productella* (*Strophalosia*?) *truncata* Whiteaves, p. 112, pl. 16, figs. 1-2.

1892b *Strophalosia truncata* Beecher; Hall & Clarke, p. 316, pl. 15B, figs. 24-26; pl. 17, figs. 10-15.

1896 *Productella truncata*; Kindle, p. 35.

1958 *Productella truncata*; Stumm & Wright, p. 92.

Types. Hall's (1857) original description did not include a holotype designation or specimen illustrations, but did indicate that the specimens upon which his desciptions were based were from calcareous shales near the base of the Hamilton Group in Schoharie and Onondaga Counties, and shore of Lake Erie above Buffalo, New York. Original types cannot be traced from previous references.

Description. Shell medium-sized, concavo-convex, slightly transversely extended;

hinge line straight, shorter than the maximum width; ornament concentric, weak ventrally.

Ventral valve gibbous in the middle region of the shell, broadly truncate on the umbo, narrow flattened ears forming at the cardinal extremities, separated by lateral ridges; ventral surface covered by slender spines, suberect, semirecumbent; ventral sulcus inconspicuous; ventral interarea linear; anterior commissure uniplicate.

Ventral interior unknown.

Dorsal valve moderately to strongly concave; fold inconspicuous; dorsal interarea linear.

Dorsal valve interior with conspicuous depression at the umbonal range; interior wall not smooth, wrinkled and pustulose; cardinal process short, bilobed.

Material. Total 38 incomplete specimens.

Occurrence. Arkona Shale Formation; Arkona-Thedford-Ipperwash area, southwestern Ontario.

Discussion. Hall and Clarke (1892b) assigned this species to the genus *Strophalosia.* In terms of external features of the shell, one distinctive characteristic of the genus *Strophalosia* is a wide ventral interarea (Howard et al., 2000, p. 565), which differs markedly from the narrower (linear) the ventral interarea of *P. truncata*. *Strophalosia* also has a weak concavo-convex profile (Howard et al., 2000, p. 565), whereas *P. truncata* is more strongly concavo-convex. In terms of internal shell features, all species assigned to the genus *Strophalosia* have a medium septum connected to the cardinal process and adductor scars reaching two-thirds disk length. Hall's (1867) figures that illustrate the interior characters of the dorsal valve of *P. truncata*, indicate no such characters; rather, a conspicuous depression is present at the umbonal region of this species (Hall, 1867, pl. 23, figs. 12, 13, 21, and 22). In addition, the age range of the genus *Strophalosia* is from the Lower Permian (Sakmarian) to the Upper Permian (Kazanian), which is clearly at odds with the Middle Devonian age of the taxon described above.

Suborder STROPHALOSIIDINA Schuchert, 1913a

Superfamily STROPHALOSIOIDEA Schuchert, 1913a

Family ARAKSALOSIIDAE Lazarev, 1989

Subfamily DONALOSIINAE Lazarev, 1989

Genus *Devonalosia* Muir-Wood and Cooper, 1960

Type species: *Devonalosia wrightorum* Muir-Wood & Cooper, 1960, upper Arkona Shale Formation, Middle Devonian Hamilton Group, Arkona, Ontario, Canada.

Devonalosia wrightorum Muir-Wood & Cooper, 1960

Pl. 2-2, figs. 1-5; Table 2-8; Fig. 2-10; Fig. 2-11

1960 *Devonalosia wrightorum* Muir-Wood & Cooper, p. 85, pl. 1, figs. 1-19.

Types. Holotype USNM 123431, Arkona Shale Formation, Middle Devonian Hamilton Group, Ontario, Canada.

Description. Shell medium-sized, subcircular, concavo-convex; anterior commissure rectimarginate.

Ventral valve moderately convex; surface covered with thick spines, recumbent anteriorly, about 3-4 mm long, organized concentrically; sulcus absent, interarea with flat pseudodeltidium.

Ventral interior with strong teeth; ventral diductor scars impressed.

Dorsal valve moderately concave, surface marked by dimples and concentric growth lamellae; spines usually absent; chilidium absent.

Dorsal interior with bilobed cardinal process; dorsal median septum stout, present between brachial impressions (Figure 2-10).

Material. Total 51 complete specimens and 12 incomplete specimens.

Occurrence. Arkona Shale Formation; Arkona-Thedford-Ipperwash area, southwestern Ontario.

Discussion. Muir-Wood and Cooper (1960) compared *Devonalosia wrightorum* Muir-Wood & Cooper, 1960 from the upper Arkona Shale Formation of the Middle Devonian Hamilton Group of Ontario and *D. radicans* (Winchell, 1863) from the Gravel Point Formation of the Middle Devonian Traverse Group of Michigan. They stated that *D. wrightorum* differs from *D. radicans* in its larger size and more circular outline. Another diference is that the ventral valve in *D. radicans* is usually completely attached by clasping spines, rather than prostrate and recumbent spines (as observed in *D. wrightorum*), and the dorsal valve in *D. radicans* lacks the dimples and concentric growth lamellae that are present in *D. wrightorum* (Muir-Wood and Cooper, 1960, p. 85).

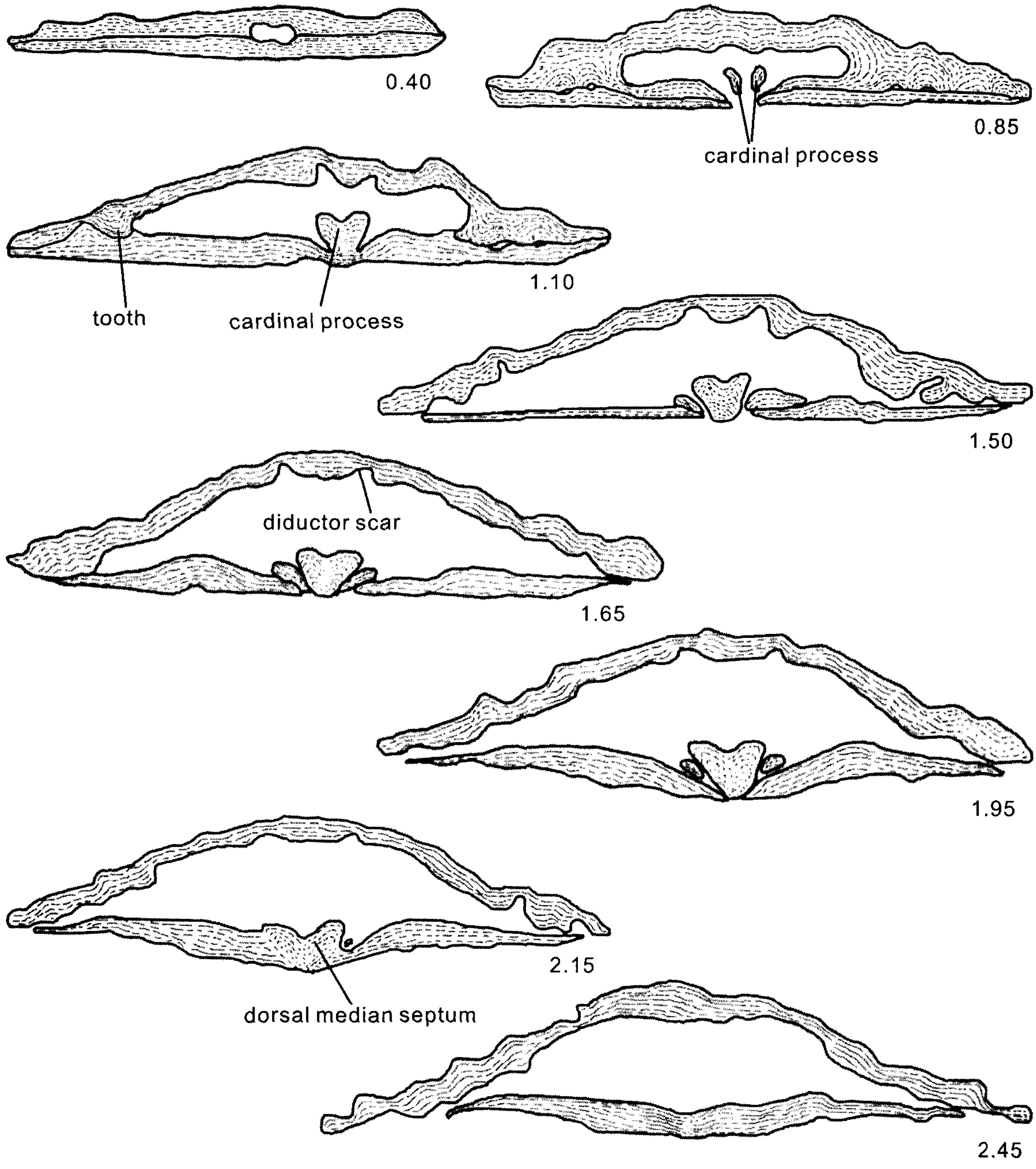


Fig. 2-10. Selected transverse serial sections of *Devonalosia wrightorum* Muir-Wood & Cooper, 1960. UMMP 74032. Arkona Shale. Hungry Hollow. Distances in mm from posterior tip of ventral umbo. X8.0

	W	L	T	L/W	T/W
MEAN	13.06	10.14	3.74	0.78	0.29
STD	1.52	1.18	0.61	0.05	0.03
MIN	9.19	6.97	1.92	0.64	0.19
MAX	15.28	12.98	4.70	0.88	0.37
N	38	38	38	38	38

Table 2-8. Statistical data of shell dimensions (mm) for complete specimens of *Devonalosia wrightorum* Muir-Wood & Cooper, 1960, sample from Collecting locality 2, Arkona Shale Formation.

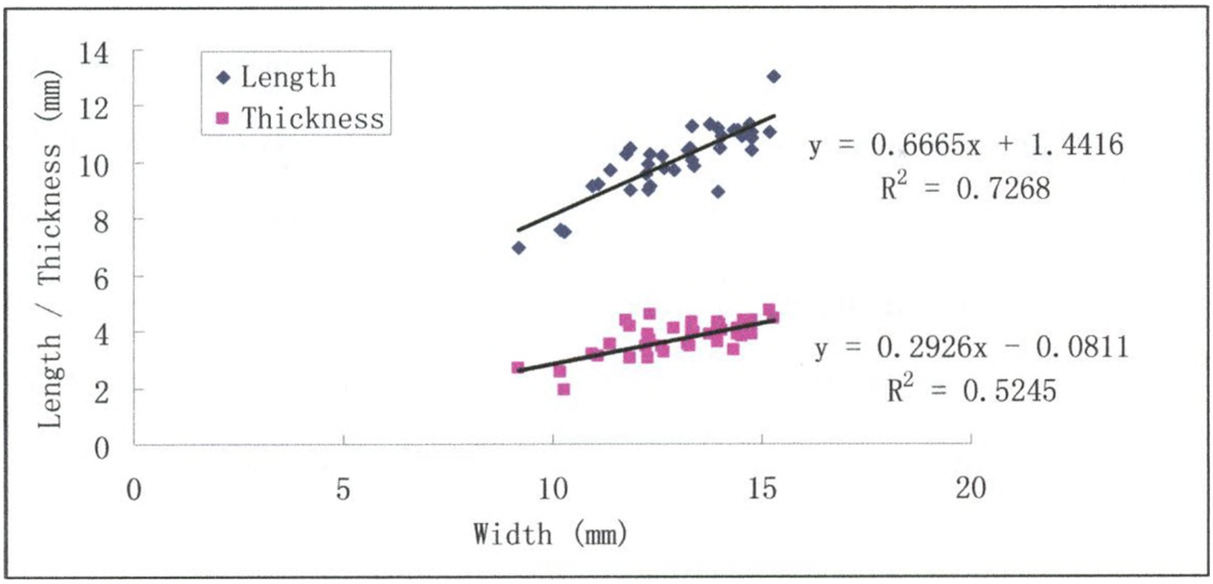


Fig. 2-11. Length-width and thickness-width graphs for complete specimens of *Devonalosia wrightorum* Muir-Wood & Cooper, 1960, sample from Collecting locality 2, Arkona Shale Formation.

Order ORTHOTETIDA Waagen, 1884

Suborder ORTHOTETIDINA Waagen, 1884

Superfamily CHILIDIOPSOIDEA Boucot, 1959a

Family AREOSTROPHIIDAE Manankov, 1979

Subfamily ADECTORHYNCHINAE Henry & Gordon, 1985

Genus *Floweria* Cooper & Dutro, 1982

Type species: *Orthis pravus* Hall, 1858, calcareous shale, Middle Devonian Hamilton Group, Lime Creek, Worth County, Iowa, U. S. A..

Floweria arctostriata (Hall, 1843)

Pl. 2-9, figs. 1-5; Table 2-9; Fig. 2-12

1843 *Strophomena arctostriata* Hall, p. 266, fig. 3.

1860 *Orthisina arctostriata*; Hall, p. 80.

1867 *Streptorhynchus arctostriata*; Hall, p. 71. pl. 9, figs. 1-12.

1877 *Hemipronites chemungensis arctostriata*; Meek, p. 35, pl. 3, fig. 2.

1884 *Streptorhynchus arctostriata*; Walcott, p. 177, pl. 13, fig. 7.

1892b *Orthothetes chemungensis* var. *arctostriata*; Hall & Clarke, pl. 10, fig. 8.

1902 *Orthothetes arctostriatus*; Shimer & Grabau, p. 182.

1909 *Schuchertella arctostriata*; Grabau & Shimer, p. 229-230, fig. 280a-280b.

1911 *Schuchertella chemungensis arctostriata*; Cleland, p. 91, pl. 16, fig. 15.

1922 *Schuchertella arctostriata*; Branson, p. 83-84, pl. 15, figs. 8, 9, 12; pl. 24, figs. 18-23.

1958 *Schuchertella arctostriata*; Stumm & Wright, p. 116.

1965 *Schuchertella arctostriata*; Griesemer, p. 264, 266, pl. 3, figs. 5-6.

1994 *Eoschuchertella arctostriata*; Linsley, p. 75, pl. 74, figs. 1-11.

2005 *Floweria arctostriata*; Rode, p. 162-163, fig. 9. 4.

Types. Hall's (1843) original description did not designate a holotype, but the original specimen figured by Hall (1843) is stated to be from the Upper Devonian Chemung Group (exact horizon unknown), Hobbieville, New York. AMNH 30605 was designated by Rode (2005) as "holotype by monotypy".

Description. Shell medium to large, slightly biconvex to planoconvex, subquadrate; surface of shell covered by numerous sharp plications, increasing by intercalation; surface of shell also marked by concentric lamellose growth lines; growth lines more frequent at anterior portion of the shell; hinge line straight, slightly less or equal to the maximum shell width.

Ventral valve more or less convex at the umbonal region, becoming concave or flattened anteriorly; ventral interarea relatively high (4.7 ~ 5.6 mm), anacline; pseudodeltidium convex; horizontal growth lines present on both the interarea and the pseudodeltidium.

Ventral interior with short hinge teeth; ventral muscle field wide, flabellate, deeply impressed.

Dorsal valve slightly convex to flatten; dorsal fold inconspicuous; dorsal interarea short, reduced; chilidium present.

Dorsal interior with well developed myophore; dorsal muscle field long, separated by myophore.

Material. Total 50 complete specimens.

Occurrence. Arkona Shale Formation; Widder Formation; Arkona-Thedford-Ipperwash

area, southwestern Ontario.

Discussion. Floweria anomala (Winchell, 1866) from the Middle Devonian Traverse Group of Michigan (Ehlers & Kline, 1934, p. 154-156, pl. 1, figs. 20-27; pl. 3, figs. 1-2) differs from *F. arctostriata* (Hall, 1843) in having a deeply concave ventral valve, and by its different outline, the former reaching its maximum shell width at a point slightly posterior to the middle of the shell. *F. varicostata* (Fagerstrom, 1961) from the Middle Devonian Formosa Reef Limestone of southwestern Ontario (Fagerstrom, 1961, p. 21, pl. 8, figs. 19-25) differs from *F. arctostriata* in ornamentation. The radial ornamentation of *F. varicostata* consists of two orders of costae, primary costae, which are sharply elevated and range from twelve to sixteen in number, and rounded secondary costae, which are less pronounced. The secondary costae (almost none in some specimens while others have one) emerge between primary costae by intercalation. This character is unknown in any other species of the genus (Fagerstrom, 1961, p. 21). Although *F. cornucopia* (Imbrie, 1959) from the Genshaw Formation of the Middle Devonian Traverse Group of Michigan (Imbrie, 1959, p. 391, pl. 62, figs. 5-8) also has high ventral interarea, it is distinguishable from *F. arctostriata* (Hall, 1843) by its elongate outline, irregularly subconical ventral valve, and more prominent lamellose growth lines.

	W	L	T	W_1	L/W	T/W	W_1/W
MEAN	18.71	14.56	5.09	15.59	0.78	0.28	0.83
STD	4.45	3.51	1.67	4.41	0.05	0.06	0.06
MIN	8.84	7.31	2.80	6.16	0.70	0.19	0.70
MAX	26.43	19.20	8.34	24.66	0.85	0.39	0.93
N	15	15	12	14	15	12	14

Table 2-9. Statistical data of shell dimensions (mm) for complete specimens of *Floweria arctostriata* (Hall, 1843), sample from Collecting locality 2, Arkona Shale Formation.

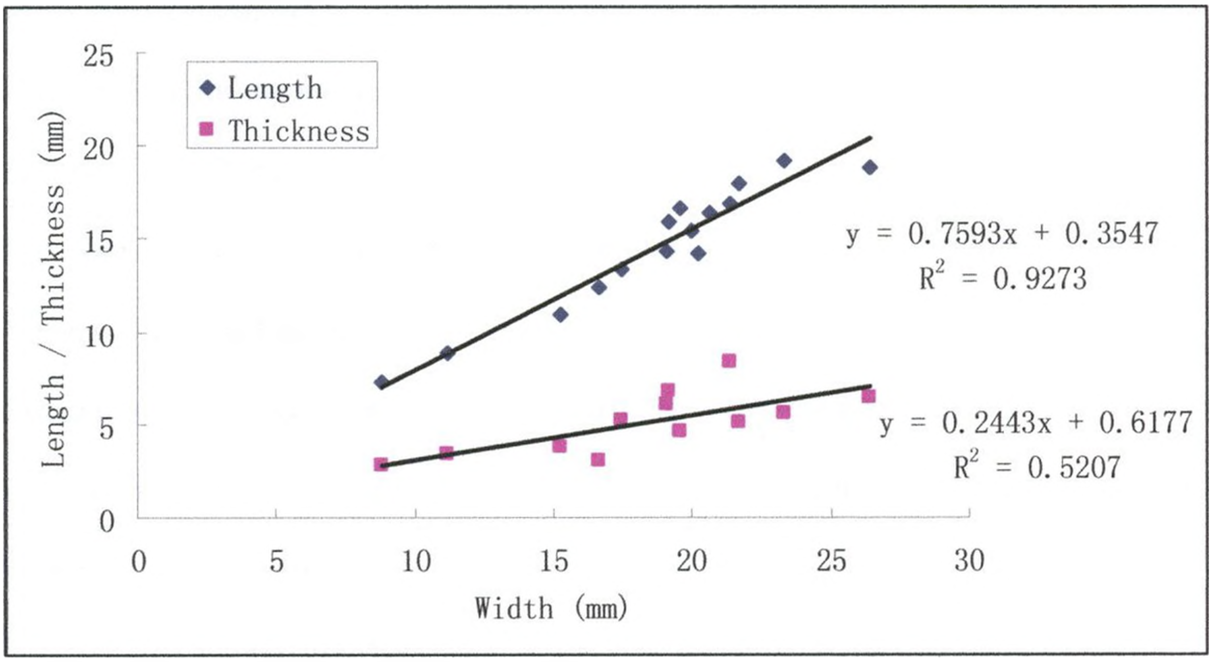


Fig. 2-12. Length-width and thickness-width graphs for complete specimens of *Floweria arctostriata* (Hall, 1843), sample from Collecting locality 2, Arkona Shale Formation.

Floweria sp.

Pl. 2-9, figs. 6-10

Description. Shell medium to large, planoconvex, subquadrate; surface of shell covered by numerous fine plications, increasing by intercalation (at the mid-length of shell, 6 - 7 in number per 5 mm); growth lines weak; hinge line straight, slightly less than the maximum width.

Ventral valve moderately convex in the umbonal range, concave or flattened towards the front and sides of the shell; ventral interarea low (~ 1.5 mm), anacline; pseudodeltidium convex; on both the interarea and the pseudodeltidium, horizontal growth lines present but weak.

Ventral interior unknown.

Dorsal valve slightly convex to flatten; dorsal fold inconspicuous; dorsal interarea linear, chilidium present.

Dorsal interior unknown.

Material. Total 7 incomplete specimens.

Occurrence. Coral unit, Hungry Hollow Member, Widder Formation; Arkona-Thedford-Ipperwash area, southwestern Ontario.

Discussion. This species is easily distinguishable from congeneric species by its quite thin outline. Although *F. murphyi* (Chatterton, 1973) from the Early–Middle Devonian Murrumbidgee Group, Taemas, New South Wales (Chatterton, 1973, p. 63-64, pl. 14, figs. 1-17) is similar in shape to this species, it differs from the latter species in its smaller size, thicker shell, less denser costellae, and higher ventral interarea.

Order ORTHIDA Schuchert & Cooper, 1932

Suborder DALMANELLIDINA Moore, 1952

Superfamily DALMANELLOIDEA Schuchert, 1913b

Family RHIPIDOMELLIDAE Schuchert, 1913b

Subfamily RHIPIDOMELLINAE Schuchert, 1913b

Genus *Rhipidomella* Oehlert, 1890

Type species: *Terebratula michelini* Léveillé, 1835, Viséan (exact horizon and locality unknown, Carboniferous), Belgium–France.

Rhipidomella vanuxemi (Hall, 1857)

Pl. 2-10, figs. 1-7; Table 2-10; Fig. 2-13; Fig. 2-14

1857 *Orthis vanuxemi* Hall, p. 135, figs. 1-7.

1858 *Orthis vanuxemi*; Hall, p. 487, pl. 2, figs. 2, 3.

1860 *Orthis vanuxemi*; Billings, p. 269.

1862 *Orthis vanuxemi*; Winchell, p. 409.

1867 *Orthis vanuxemi*; Hall, p. 40, 47, pl. 5, fig. 6; pl. 6, fig. 3.

1883 *Orthis vanuxemi*; Hall, pl. 36, figs. 14, 15.

1889 *Orthis vanuxemi*; Whiteaves, p. 123

1889 *Orthis vanuxemi*; Nettelroth, p. 45, pl. 16, figs. 4-6, 12-14.

1892b *Rhipidomella vanuxemi*; Hall & Clarke, p. 225, pl. 6, figs. 14, 15; pl. 6A, figs. 7, 8.

1902 *Rhipidomella vanuxemi*; Shimer & Grabau, p. 182.

1915 *Rhipidomella vanuxemi*; Stauffer, p. 89.

1958 *Rhipidomella vanuxemi*; Stumm & Wright, p. 108, 121.

1963 *Rhipidomella vanuxemi*; Wright & Wright, p. 123.

1969 *Rhipidomella vanuxemi*; Harper, Boucot & Walmsley, p. 75, text-fig. 1, b.

Types. In his original description, Hall (1857) illustrated specimens from shale beds and shaly sandstone beds of the Middle Devonian Hamilton Group, New York, did not designate a holotype. Original types cannot be traced from previous references.

Description. Shell medium-sized, dorsibiconvex, sub-trapezoid to subcircular, slightly transversely extended; shell covered with numerous, fine and rounded plications (at the mid-length of shell, 6-8 in number per 2 mm), increasing by bifurcation and crossed by sparse, irregular lamellose growth lines; growth lines more frequent at the anterior range; anterior commissure weakly unisulcate to rectimarginate.

Ventral valve moderately convex in the umbonal region, becoming flat or lightly concave anteriorly; sulcus inconspicuous; hinge line well-developed; ventral interarea low (1.5 - 1.9 mm), curved, apsacline; horizontal fine growth lines present within interarea; beak small, slightly curved.

Ventral interior marked by a large flabelliform muscular impression, reaching from one half up to two thirds the length of the shell; dental plates recessive, divergent, becoming parallel anteriorly; teeth strong.

Dorsal valve moderately convex; very shallow depression present at the middle of the shell, widening anteriorly; notothyrium covered by chilidial plates; dorsal interarea vestigial.

Dorsal interior with a strong cardinal process, supported by median ridge; median ridge having a half length of shell; muscular impression divided by a thick median ridge; median ridge becoming lower anteriorly. Brachiophores thick, rod-shaped (

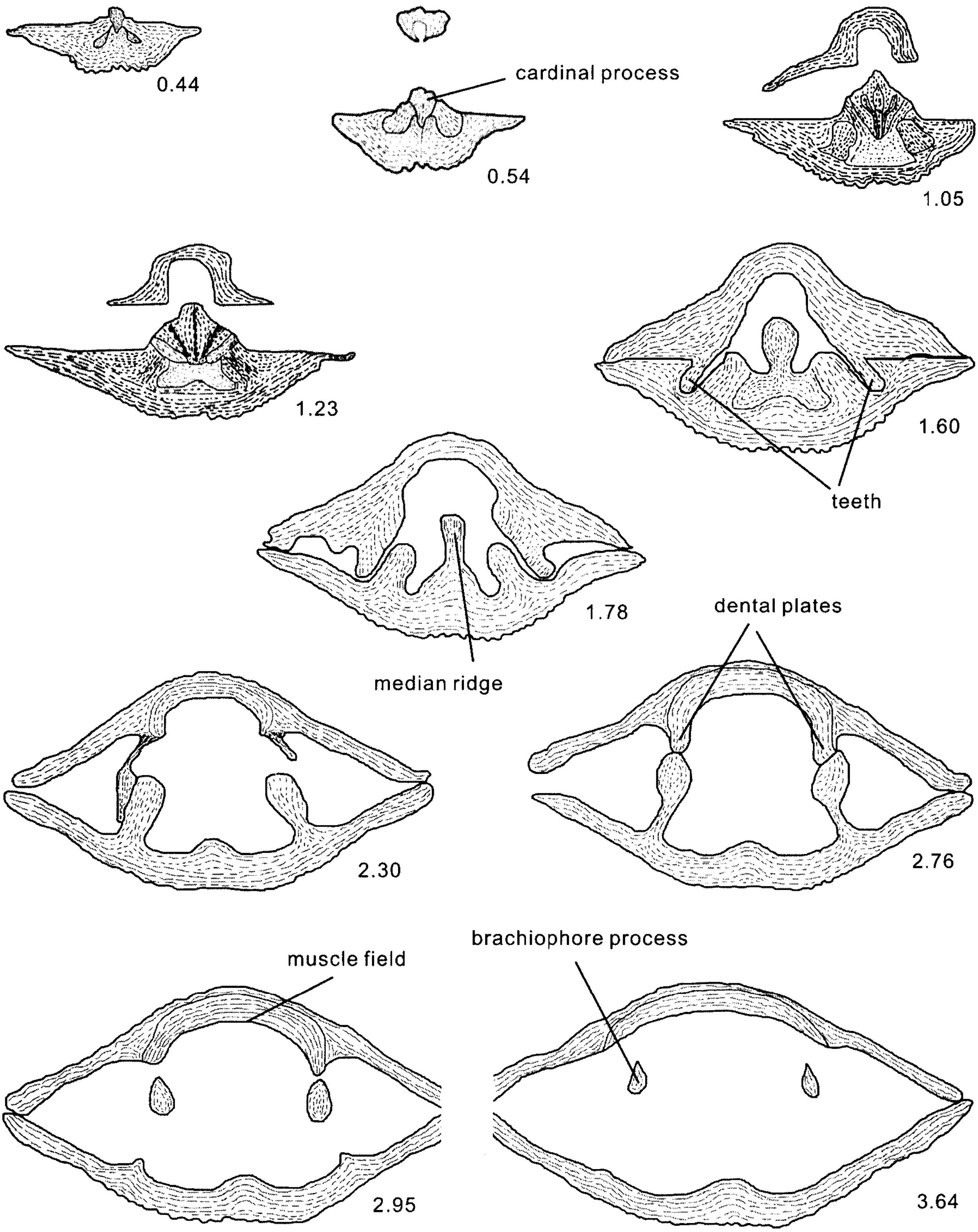


Fig. 2-13. Selected transverse serial sections of *Rhipidomella vanuxemi* (Hall, 1857). W 2901. Ipperwash Limestone. Collecting locality 9. Distances in mm from posterior tip of ventral umbo. X6.0

	W	L	T	W_1	L/W	T/W	W_1/W
MEAN	13.98	12.80	4.53	4.71	0.91	0.31	0.33
STD	4.31	4.10	2.51	1.84	0.04	0.09	0.04
MIN	8.03	7.50	1.58	2.60	0.82	0.16	0.23
MAX	26.51	25.03	11.07	10.87	0.99	0.50	0.45
N	43	43	43	43	43	43	43

Table 2-10. Statistical data of shell dimensions (mm) for complete specimens of *Rhipidomella vanuxemi* (Hall, 1857), sample from Collecting locality 9, Ipperwash Limestone.

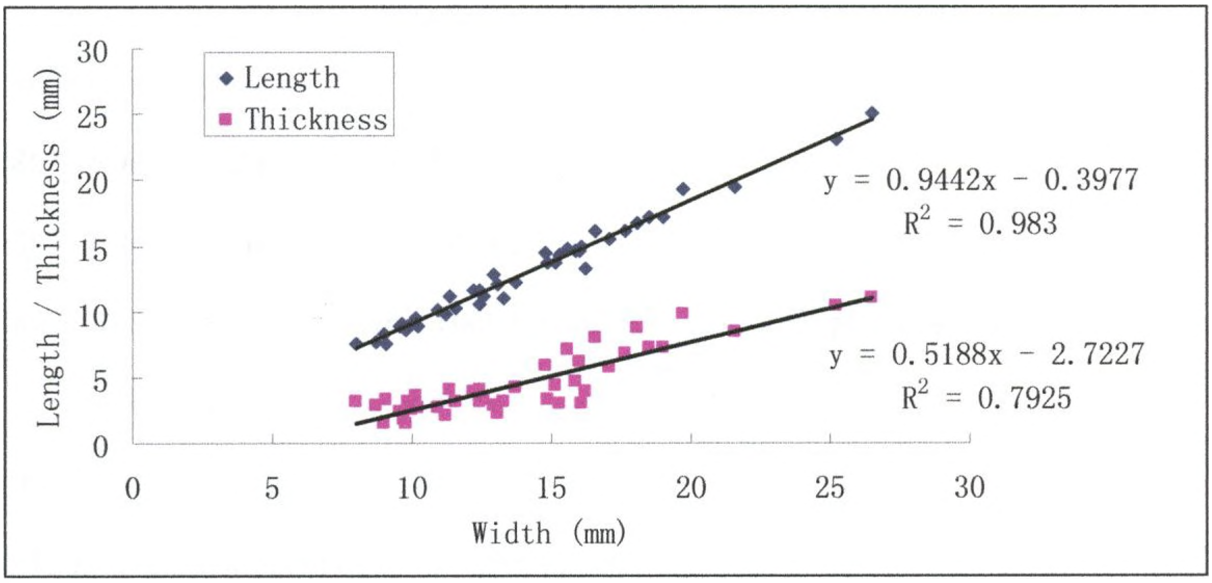


Fig. 2-14. Length-width and thickness-width graphs for complete specimens of *Rhipidomella vanuxemi* (Hall, 1857), sample from Collecting locality 9, Ipperwash Limestone.

Figure 2-13).

Material. Total 240 complete specimens, 5 incomplete ventral valves, 4 complete dorsal valves and 7 incomplete dorsal valves.

Occurrence. Widder Formation; Ipperwash Limestone; Arkona-Thedford-Ipperwash area, southwestern Ontario.

Discussion. Rhipidomella trigona Imbrie, 1959 from the Middle Devonian Traverse Group of Michigan (Imbrie, 1959, p. 368, pl. 49, figs. 13-18) is distinguished from *R. vanuxemi* (Hall, 1857) by its subtrigonal outline, equal width and length (measurements of the Holotype: length of the ventral valve: 12.7 mm; width: 12.7 mm; thickness: 8.5 mm), higher ventral interarea, and strongly, evenly convex dorsal valve.

Rhipidomella penelope (Hall, 1860)

Pl. 2-10, figs. 8-13; Table 2-11; Fig. 2-15; Fig. 2-16

1860b *Orthis penelope* Hall, p. 79, figs. 1-2.

1867 *Orthis penelope*; Hall, p. 50, pl. 6, fig. 2.

1883 *Orthis penelope*; Hall, pl. 36, figs. 6-13.

1892b *Rhipidomella penelope*; Hall & Clarke, p. 211, 225, pl. 6, figs. 6-13; pl. 6A, fig. 10(?11).

1902 *Rhipidomella penelope*; Shimer & Grabau, p. 182.

1915 *Rhipidomella penelope*; Stauffer, p. 160.

1944 *Rhipidomella penelope*; Shimer & Shrock, p. 355, pl. 139, figs. 21-23.

1958 *Rhipidomella penelope*; Stumm & Wright, p. 92, 107, 121.

Types. Original specimens figured by Hall (1860b) were from shale beds of the Hamilton Group, western New York, but the author did not designate a holotype. Original types cannot be traced from previous references.

Description. Shell large-sized, subcircular, plano-convex; shell covered with numerous, fine and bifurcating plications (at the mid-length of shell, 4-6 in number per 2 mm), crossed by irregular lamellose growth lines; growth lines more frequent at the anterior region; anterior commissure weakly unisulcate to rectimarginate.

Ventral valve moderately convex at the umbonal range, becoming flat to regularly concave anteriorly; sulcus inconspicuous; hinge line well-developed, about two fifths the width of the shell; ventral interarea low to relatively high (1.2 ~ 2.8 mm), curved, apsacline; horizontal fine growth lines present within interarea; beak small, slightly curved.

Ventral interior marked by a subcircular flabellate muscular impression, distinctly pitted or rugose in curving ridges; dental lamella prominent, connected with the raised border of the muscular impression; dental plates recessive, sub-parallel; teeth strong.

Dorsal valve moderately convex; the greatest convexity at the central of shell, with a very shallow depression or flattening; notothyrium covered by chilidial plates; dorsal interarea vestigial.

Dorsal interior with strong, prominent cardinal process; the muscular impression broadly oval, foliate, with relatively lower margins; muscular impression divided by the thick median ridge; median ridge becoming lower anteriorly; brachiophores thick, becoming blade-shaped anteriorly (Figure 2-15).

Material. Total 165 complete specimens, 34 incomplete specimens, and 2 complete ventral valves.

Occurrence. Widder Formation; Ipperwash Limestone; Arkona-Thedford-Ipperwash area, southwestern Ontario.

Discussion. Compared with *Rhipidomella vanuxemi* (Hall, 1857) (Table 2-10), *R. penelope* (Hall, 1860) is larger in size (Table 2-11), and features stronger plications on the shell exterior; For the shell interior, the muscular impression in the ventral valve of *R. penelope* is broader and more strongly marked (Pl. 2-10, fig. 13); the cardinal and brachial processes in dorsal valve of *R. penelope* (Figure 2-15) are more prominent than those in dorsal valve of *R. vanuxemi* (Figure 2-13). *R. penelope traversensis* Imbrie, 1959 from the Four Mile Dam Formation of the Middle Devonian Traverse Group of Michigan (Imbrie, 1959, p. 367-368, pl. 48, figs. 24-27) differs from *R. penelope* in having smaller size (the measurements of holotype: length of the ventral valve: 10 mm; width: 11 mm; thickness: 4 mm) and a transversely elliptical outline.

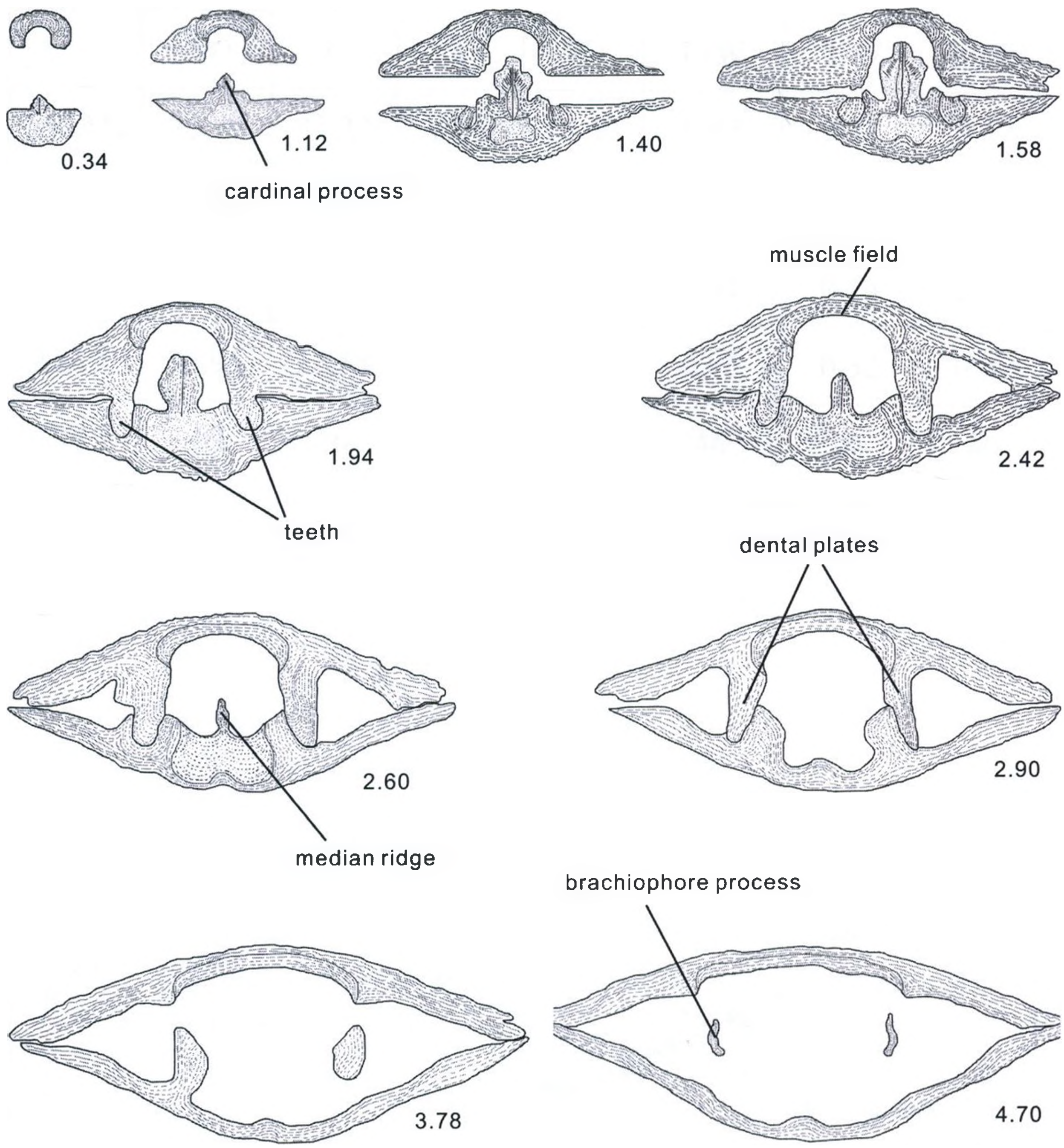


Fig. 2-15. Selected transverse serial sections of *Rhipidomella penelope* (Hall, 1860). W 2904. Ipperwash Limestone. Collecting locality 9. Distances in mm from posterior tip of ventral umbo. X3.5

	W	L	T	W_1	L/W	T/W	W_1/W
MEAN	26.79	23.32	6.08	11.42	0.87	0.23	0.42
STD	5.49	4.70	1.79	2.71	0.03	0.04	0.03
MIN	14.57	13.26	2.40	6.15	0.81	0.14	0.37
MAX	36.95	32.35	10.47	17.67	0.95	0.32	0.49
N	46	46	46	40	46	46	40

Table 2-11. Statistical data of shell dimensions (mm) for complete specimens of *Rhipidomella penelope* (Hall, 1860), sample from Collecting locality 9, Ipperwash Limestone.

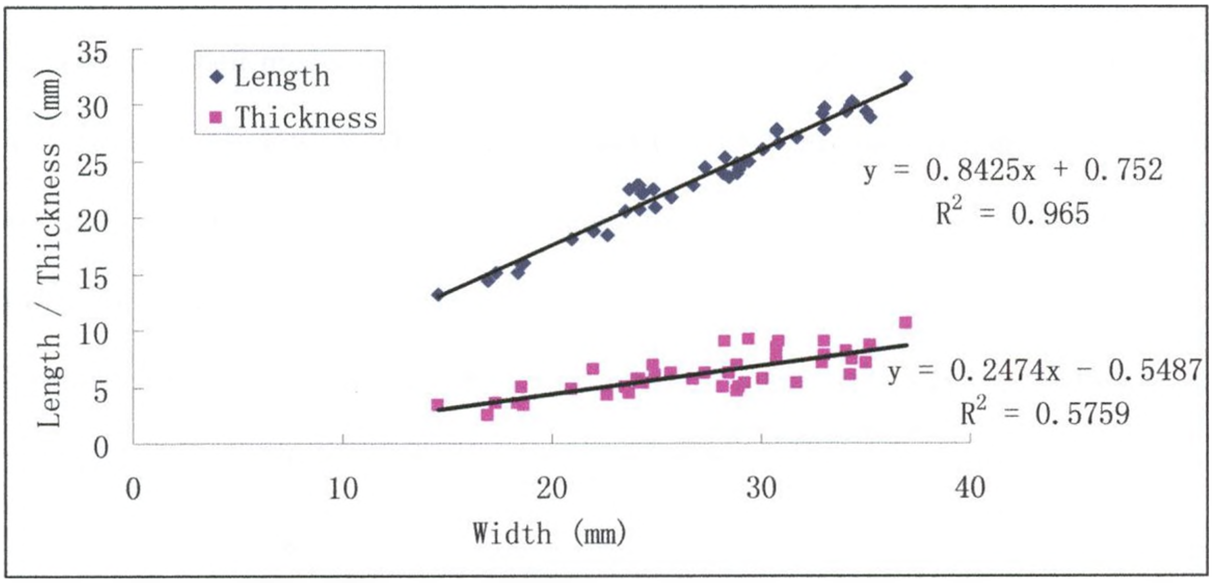


Fig. 2-16. Length-width and thickness-width graphs for complete specimens of *Rhipidomella penelope* (Hall, 1860), sample from Collecting locality 9, Ipperwash Limestone.

Order PENTAMERIDA Schuchert & Cooper, 1931

Suborder PENTAMERIDINA Schuchert & Cooper, 1931

Superfamily CLORINDOIDEA Rzhonsnitskaia, 1956

Family CLORINDIDAE Rzhonsnitskaia, 1956

Subfamily PENTAMERELLINAE Sapelnikov, 1973

Genus *Pentamerella* Hall, 1867

Type species: *Atrypa arata* Conrad, 1841, Schoharie Formation (Devonian), Albany County, New York.

Pentamerella cf. *pavilionensis* (Hall, 1860)

Pl. 2-8, figs. 1-5

Types. Hall's (1860) original description of *Pentamerella pavilionensis* was based on specimens from shale beds of the Hamilton Group of western New York, but the author included neither illustrations of the specimens used nor a holotype. Original types cannot be traced from previous references.

Description. Shell medium-sized, ventribiconvex, subpentagonal in outline; surface of shell covered by low, thick rounded plications (3-5 in number per flank), more prominent at anterior portion of shell; hinge line short; cardinal extremities rounded; maximium width at mid-length; anterior commissure uniplicate.

Ventral umbonal region strongly convex; ventral sulcus very shallow to ill-defined; interarea low, apsacline.

Ventral interior unknown.

Dorsal valve moderately convex; fold inconspicuous; interarea linear.

Dorsal interior unknown.

Material. Total 5 incomplete specimens.

Occurrence. Coral Unit, Hungry Hollow Member, Widder Formation; Arkona-Thedford-Ipperwash area, southwestern Ontario.

Discussion. Pentamerella cf. *pavilionensis* (Hall, 1860) is distinguishable from *P. pavilionensis* (Hall, 1860) from the Middle Devonian Formosa Reef Limestone of southerwestern Ontario (Fagerstrom, 1961, p. 18, pl. 7, figs. 7-30) by its subpentagonal outline, fewer plications, inconspicuous plications at posterior portion of shell, and inconspicuous fold. *P. grandis* Fagerstrom, 1961 from the Middle Devonian Formosa Reef Limestone of southerwestern Ontario (Fagerstrom, 1961, p. 18 - 19, pl. 7, figs. 31 - 33) differs from *P.* cf. *pavilionensis* in having a very large size for the genus, incurved beak, and more prominent sulcus. *P. multicosta* Cleland, 1911 from the Middle Devonian rocks of southeastern Wisconsin (Griesemer, 1965, p. 259, pl. 2, figs. 11-12) differs from *P.* cf. *pavilionensis* in that its ventral valve is much more convex and radial costae more prominent. Compared to *P.* cf. *pavilionensis*, *P. lingua* Imbrie, 1959 from the Ferron Point Formation of the Middle Devonian Traverse Group of Michigan (Imbrie, 1959, p. 370, pl. 52, figs. 6-10) is larger in size (measurements of the holotype: length of ventral valve: 27 mm; width: 26 mm; thickness: 16 mm), with stronger, more costae on the shell surface (~13 in number on mature shell) and more prominent fold and sulcus. *P. tumida* Imbrie, 1959 from the Genshaw Formation of the Middle Devonian Traverse Group of Michigan (Imbrie, 1959, p. 370-371, pl. 52, figs. 19-23) differs from *P.* cf. *pavilionensis* in its much larger size (measurements of the holotype: length of ventral valve: 43 mm; width: 40 mm; thickness: 29 mm), more strongly convex ventral valve with a more swollen umbo and strongly incurved beak, and more numerous costae at anterior portions of the shell. *P. alpenensis* Imbrie, 1959 from the Gravel Point Formation and the Four Mile Dam Formation of the Middle Devonian Traverse Group of Michigan (Imbrie, 1959, p. 371, pl. 53, figs. 9-13) is distinguishable from *P.* cf. *pavilionensis* by its subtriangular outline, subangular costae covering the anterior two-thirds of the shell (8 in number per 15 mm at the front margin), and low, but commonly distinct, fold and sulcus.

Remarks. This species is rare in the Coral Unit of the Hungry Hollow Member (Widder Formation) within the study area. All the five individuals are incomplete and have been compressed to some extent.

Order RHYNCHONELLIDA Kuhn, 1949

Superfamily RHYNCHOTREMATOIDEA Schuchert, 1913a

Family MACHAERARIIDAE Savage, 1996

Genus *Callipleura* Cooper, 1942

Type species: *Rhynchospira nobilis* Hall, 1860, Hamilton Group (Middle Devonian), Livingston and Erie Counties, New York.

Callipleura nobilis (Hall, 1860)

Pl. 2-11, figs. 1-5; Table 2-12; Fig. 2-17; Fig. 2-18

1860b *Rhynchospira nobilis* Hall, p. 83.

1867 *Trematospira* ? *nobilis* Hall, p. 412, pl. lxiii, figs. 33-36.

1889 *Retzia* (*Trematospira*) *nobilis* (Hall); Whiteaves, vl. i, pt. 2, p. 116.

1894b *Cyclorhina nobilis*; Hall & Clarke, p. 206, pl. LXI.

1902 *Cyclorhina nobilis*; Shimer & Grabau, p. 182.

1944 *Callipleura nobilis*; Shimer & Shrock, p. 311, pl. 118, figs. 69-70.

1958 *Callipleura nobilis*; Stumm & Wright, p. 105, 115.

Types. Hall's (1860b) original description for this species was based on specimens from Hamilton Group strata of Livingston and Erie Counties, New York. He did not provide specimen illustrations, nor did he designate a holotype. Original types cannot be traced from previous references.

Description. Shell large-sized, transversely subpentagonal, dorsibiconvex; surface of shell covered by numerous, strong and angular costae (10 in number per flank, 7-9 in number in sulcus, 7-9 on the fold, 5-6 in number per 5 mm), commencing at the beak; growth lines poorly developed; anterior commissure uniplicate.

Ventral sulcus shallow, beginning from the umbonal area, widening anteriorly to occupy more than one half of shell width; foramen large and circular; interarea not developed.

Ventral interior with dental plates; dental plates distinct but partly fused to valve wall, anteriorly divergent.

Dorsal umbo moderately convex; dorsal fold low and well developed, commencing at the umbonal area.

Dorsal interior with delicate cardinal process; inner socket ridges massive; crural plates resting on valve floor; crura prominent and curved ventrally; median septum present (Figure 2-17).

Material. Total 48 complete specimens and 11 incomplete specimens.

Occurrence. Hungry Hollow Member, Widder Formation; Arkona-Thedford-Ipperwash area, southwestern Ontario.

Superfamily CAMAROTOECHIOIDEA Schuchert, 1929

Family CAMAROTOECHIIDAE Schuchert, 1929

Subfamily CAMAROTOECHIINAE Schuchert, 1929

Genus *Camarotoechia* Hall & Clarke, 1894c

Type species: *Atrypa congregata* Conrad, 1841, Conklin's Falls (exact locality and horizon unknown, Givetian (Middle Devonian)), near Apulia, Onondaga County, New York.

Camarotoechia thedfordensis Whiteaves, 1898

Pl. 2-11, figs. 6-15; Table 2-13; Fig. 2-19

1898 *Camarotoechia thedfordensis* Whiteaves, p. 386-387, pl. 48, figs. 11, 11a and 11b.

1915 *Camarotoechia thedfordensis* Whiteaves; Stauffer, p.166.

1942 *Camarotoechia thedfordensis* Whiteaves; Stumm, p. 560, figs. 14-15.

1958 *Camarotoechia thedfordensis* Whiteaves; Stumm & Wright, p. 106.

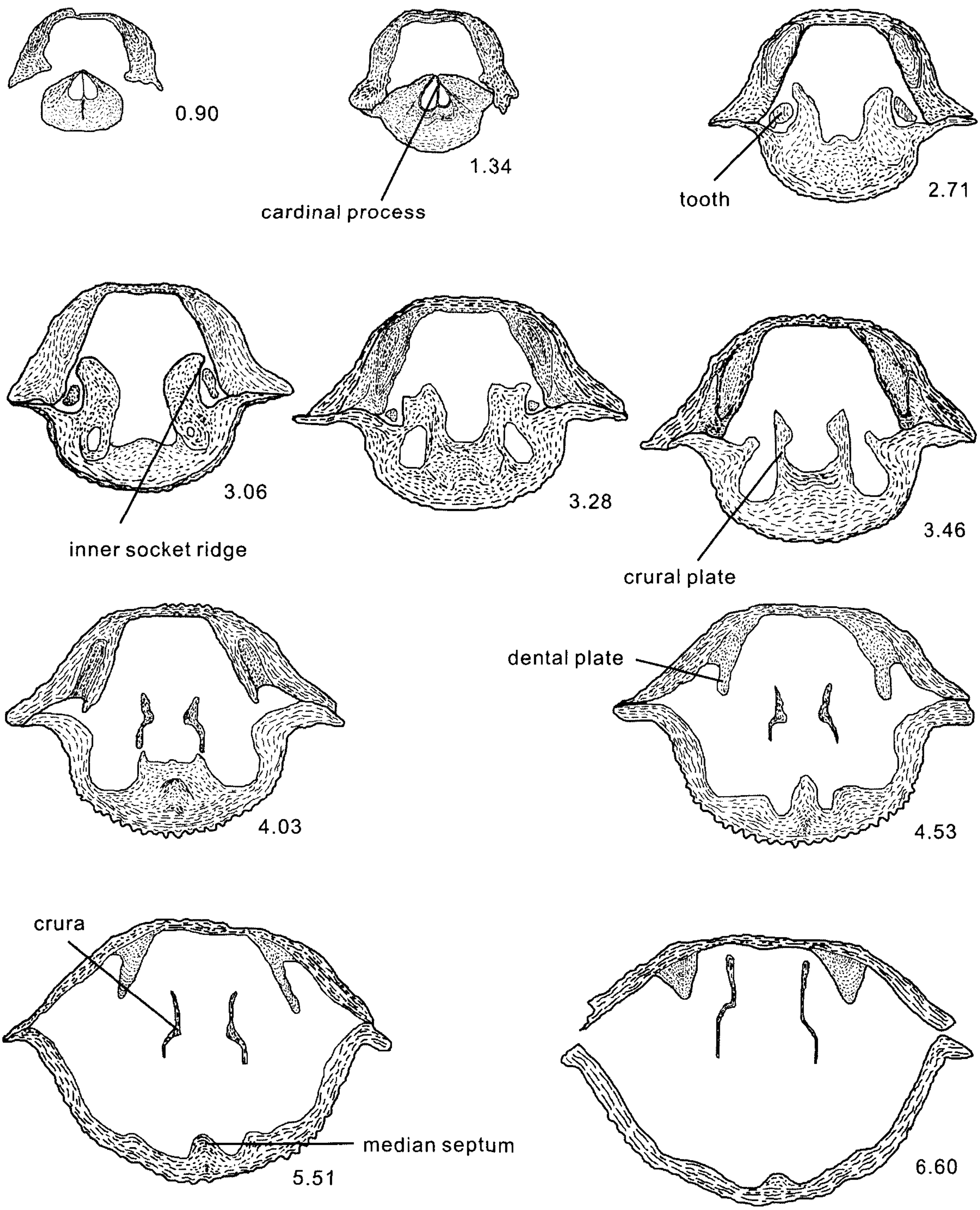


Fig. 2-17. Selected transverse serial sections of *Callipleura nobilis* (Hall, 1860). W 2858. Coral Unit, Hungry Hollow Member, Widder Formation. Collecting locality 1. Distances in mm from posterior tip of ventral umbo. X4.0

	W	L	T	L/W	T/W
MEAN	22.83	20.19	8.64	0.92	0.41
STD	8.45	6.16	4.15	0.13	0.09
MIN	7.05	7.32	3.23	0.70	0.32
MAX	32.04	29.21	18.44	1.17	0.58
N	15	16	12	14	11

Table 2-12. Statistical data of shell dimensions (mm) for complete specimens of *Callipleura nobilis* (Hall, 1860), sample from Collecting locality 1, Coral Unit, Hungry Hollow Member, Widder Formation.

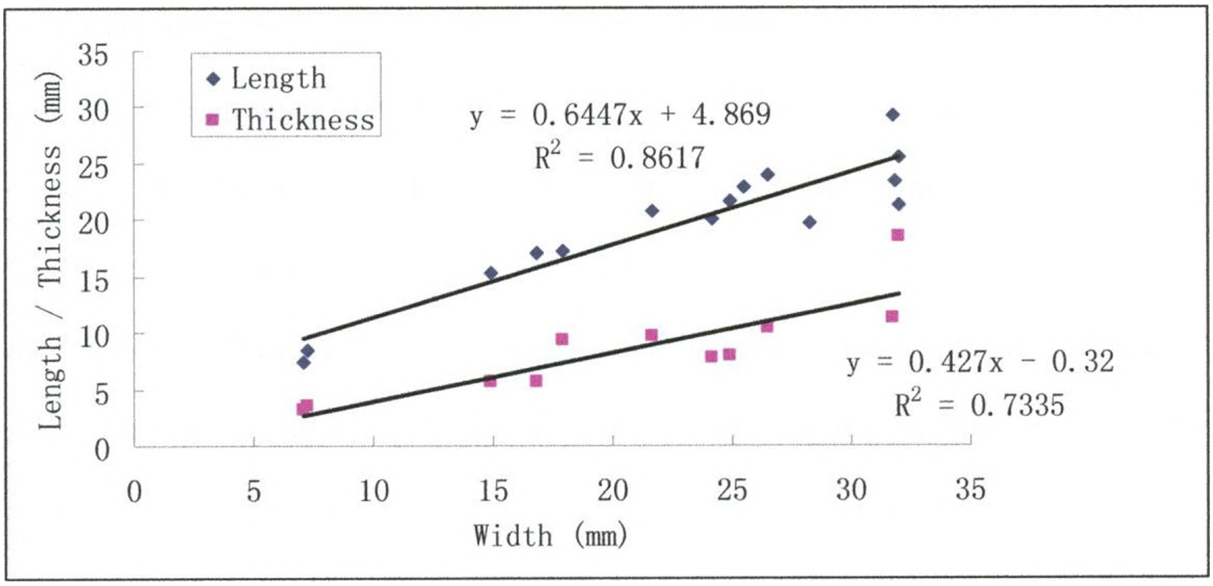


Fig. 2-18. Length-width and thickness-width graphs for complete specimens of *Callipleura nobilis* (Hall, 1860), sample from Collecting locality 1, Coral Unit, Hungry Hollow Member, Widder Formation.

Types. Syntypes GSC 3696, a-j, 1, exact locality and horizon unknown, Hamilton Group (Middle Devonian), Thedford, Ontario.

Description. Shell small, biconvex, subtriangular; shell bears simple, fine (4-5 in number per 2 mm), angular costae (4-5 on each flank, 3 in the sulcus, 4 on the fold), becoming more prominent anteriorly; maximium width at the 2/3 length from the beak; anterior commissure uniplicate, subtrapezoid-shaped tongue present in adult shells.

Ventral valve moderately convex; sulcus shallow, commencing at the umbonal area, deepening anteriorly; beak small, sharp and slightly incurved.

Ventral internal structures not preserved in the examined specimens.

Dorsal valve strongly convex; fold low, commencing at the umbonal area.

Dorsal internal structures not preserved in the examined specimens.

Material. Total 52 complete specimens and 12 incomplete specimens.

Occurrence. Hungry Hollow Member, Widder Formation; Arkona-Thedford-Ipperwash area, southwestern Ontario.

Discussion. Although the maximium width of both *Camarotoechia missouriensis* Cooper, 1945 from the Middle Devonian St. Laurent limestone, St. Laurent Creek, Petty County, Missouri (Cooper, 1945, p. 481-482, pl. 63, figs. 8-12) and *C. thedfordensis* Whiteaves, 1898 is located about two-thirds the length from their beaks, the former species differs from the latter in its subpentagonal outline, more numerous costae (10-12 in number on each flank, 5-7 in the sulcus, 6-8 on the fold), and well rounded anterior margin. *C. prolifica* (Hall) from the Hamilton Group of New York state (Hall and Clarke, 1994b, p. 192, pl. 57, figs. 42-43) is distinguishable from *C. thedfordensis* in having subpentagonal outline and more costae on the flanks (7-8 in

	W	L	T	L/W	T/W
MEAN	4.49	4.50	2.44	1.03	0.55
STD	1.09	0.79	0.61	0.14	0.10
MIN	2.48	3.02	1.57	0.83	0.43
MAX	5.74	6.05	3.43	1.25	0.74
N	16	16	16	16	16

Table 2-13. Statistical data of shell dimensions (mm) for complete specimens of *Camarotoechia thedfordensis* Whiteaves, 1898, sample from Collecting locality 5, Coral Unit, Hungry Hollow Member, Widder Formation.

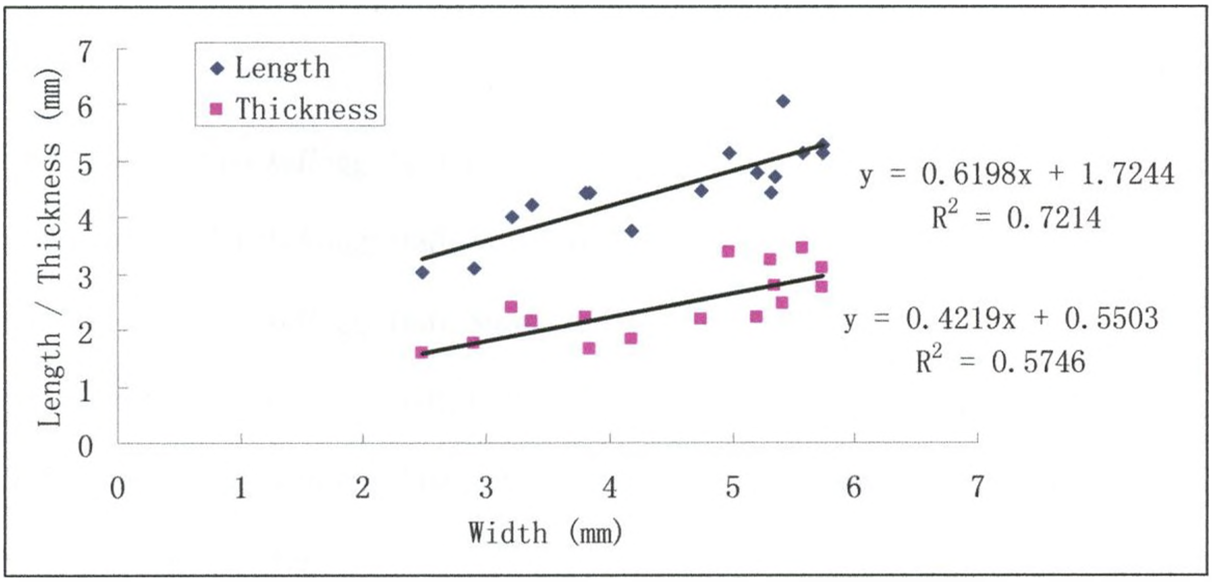


Fig. 2-19. Length-width and thickness-width graphs for complete specimens of *Camarotoechia thedfordensis* Whiteaves, 1898, sample from Collecting locality 5, Coral Unit, Hungry Hollow Member, Widder Formation.

number on each flank). Another species from the Hamilton Group of New York state, *C. sappho* (Hall) (Hall and Clarke, 1994, p. 192, pl. 57, figs. 10-14) is large for the genus, achieving a maximum width of approximately 25 mm (Shimer and Shrock, 1944, p. 311, pl. 118, figs. 57-61). Besides the much larger size, it is different from *C. thedfordensis* in having a transversely subelliptical outline and greater number of costae in the sulcus (4-6 in number).

Family LEIORHYNCHIDAE Stainbrook, 1945

Subfamily LEIORHYNCHINAE Stainbrook, 1945

Genus *Leiorhynchus* Hall, 1860a

Type species: *Orthis quadracostata* Vanuxem, 1842, Devonian black shale (exact locality and horizon unknown), New York, U.S.A..

Leiorhynchus kelloggi Hall, 1867

Pl. 1-1, fig. 5; Pl. 1-3, fig. 4

1867 *Leiorhynchus kelloggi* Hall, p. 361-362, pl. 57, figs. 1-12.

1889 *Leiorhynchus kelloggi* Hall; Miller, p. 347.

1942 *Leiorhynchus kelloggi* Hall; Stumm, pl. 81, figs. 9-10.

1951 *Leiorhynchus kelloggi* Hall; Ehlers, Stumm, & Kesling, pl. 4, figs. 21-22.

1965 *Leiorhynchus kelloggi* Hall; Driscoll, Hall, & Nussmann, p. 916, pl. 109, figs. 1-50; pl. 110, figs. 1-5.

Types. Lectotype AMNH 5702/1, Plum Brook Shale (Middle Devonian), northern Ohio, U.S.A..

Description. Shell medium to large, subovate; width greater than length; shell covered with simple, rounded costae (usually 15 ~ 20 in number in adult shells).

Ventral valve and dorsal valve unknown.

Material. Total 20 poorly-preserved moulds.

Occurrence. Top portion of the Arkona Shale Formation; Arkona-Thedford-Ipperwash area, southwestern Ontario.

Remarks. This species occurs most abundantly in the laminated black shale beds of the Arkona Shale Formation (equal to Unit 5 of the Hungry Hollow Formation of Mitchell (1967)), but are present only as compressed moulds. Based on less abundant, but undeformed specimens, from Mitchell's Unit 4 of the Hungry Hollow Formation (now included in the upper Arkona Shale Formation), Driscoll et al. (1965) assigned this species to *Leiorhynchus kelloggi* Hall, 1867.

Leiorhynchus laura (Billings, 1860)

Pl. 2-2, figs. 16-20; Pl. 2-13, figs. 1-5; Table 2-14; Fig. 2-20; Fig. 2-21

1860 *Rhynchonella*? *laura* Billings, p. 273, figs. 26-28.

1860b *Leiorhynchus multicosta* Hall, p. 85, p. 94, figs. 14-15.

1867 *Leiorhynchus multicosta*; Hall, p. 358, pl. 56, figs. 26-40.

1884 *Rhynchonella* (*Leiorhynchus*) *laura* Walcott, p. 159.

1894b *Liorhynchus multicosta*; Hall & Clarke, p. 194, pl. 59, figs. 8-10.

1894b *Liorhynchus laura*; Hall & Clarke, p. 194, pl. 59, figs. 13-17.

1927 *Leiorhynchus laura*; Ehlers & Cooley, P. 233.

1951 *Leiorhynchus laura*; Fisher, p. 369.

1961 *Leiorhynchus laura*; Wright & Wright, p. 295.

1965 *Leiorhynchus laura*; Driscoll, Hall, & Nussmann, p.926, text-fig. 10.

Types. Syntypes GSC 3705, a-k, exact locality and horizon unknown, Hamilton Group (Middle Devonian), Thedford, Ontario.

Description. Shell medium to large, biconvex, subovate; length greater than width; shell covered with simple, rounded costae (4-7 in number per flank, 3-6 in the sulcus and an equal number on the fold), crossed by numerous fine growth lines; anterior commissure uniplicate.

Ventral valve moderately to strongly convex on the umbo, forming acute apical angle (78°-87°); beak small, incurved, perforated by a small foramen; ventral sulcus shallow, commencing at the umbonal area, widening anteriorly.

Ventral interior with strong dental plates; dental plates convergent ventrally; ventral muscle field deeply impressed.

Dorsal valve moderately convex; dorsal fold low, arising at the umbonal area, widening anteriorly.

Dorsal interior with long and high median septum, supporting short septalium; crura long and small (Figure 2-20).

Material. Total 27 complete specimens and 34 incomplete specimens.

Occurrence. Widder Formation; Arkona-Thedford-Ipperwash area, southwestern Ontario.

Discussion. Driscoll et al. (1965) compared the internal structures of *Leiorhynchus* *laura* (Billings, 1860) from the Widder Formation of Arkona-Thedford area and *L. kelloggi* Hall, 1867 from uppermost beds of Silica Shale, Plum Brook Shale of Ohio and the Arkona Shale Formation of southwestern Ontario. The serial sections indicated that the shell at umbonal regions of both ventral and dorsal valves in *L. laura* is thicker than that in *L. kelloggi*. Furthermore, the shell in umbonal region of ventral valve in *L. kelloggi* is smaller than that observed in *L. laura*. Due to the considerable variation in the thickness of shell and size of the ventral valve in the umbonal region in these two species, the authors were unconvinced of the usefulness of this criterion. They indicated that a more reliable criterion on which to distinguish the two species was the marked irregularity of the internal surfaces of the ventral and dorsal valves of *L. laura* as compared to the smoother nature of these surfaces in *L. kelloggi*.

Measurements of external characters have revealed that the shell length is greater than shell width in *L. laura* (Table 2-14) whereas the opposite is true in *L. kelloggi*. *L. greeni* Cleland, 1911 from the Milwaukee Formation (Middle Devonian) of southeastern Wisconsin (Griesemer, 1965, p. 271, pl. 3, figs. 27-29) differs from *L. laura* in its subcircular outline (average length: 20.4 mm; average width: 20.6 mm; average thickness: 12.1 mm), lower fold, and trifid median septum pattern in its dorsal valve.

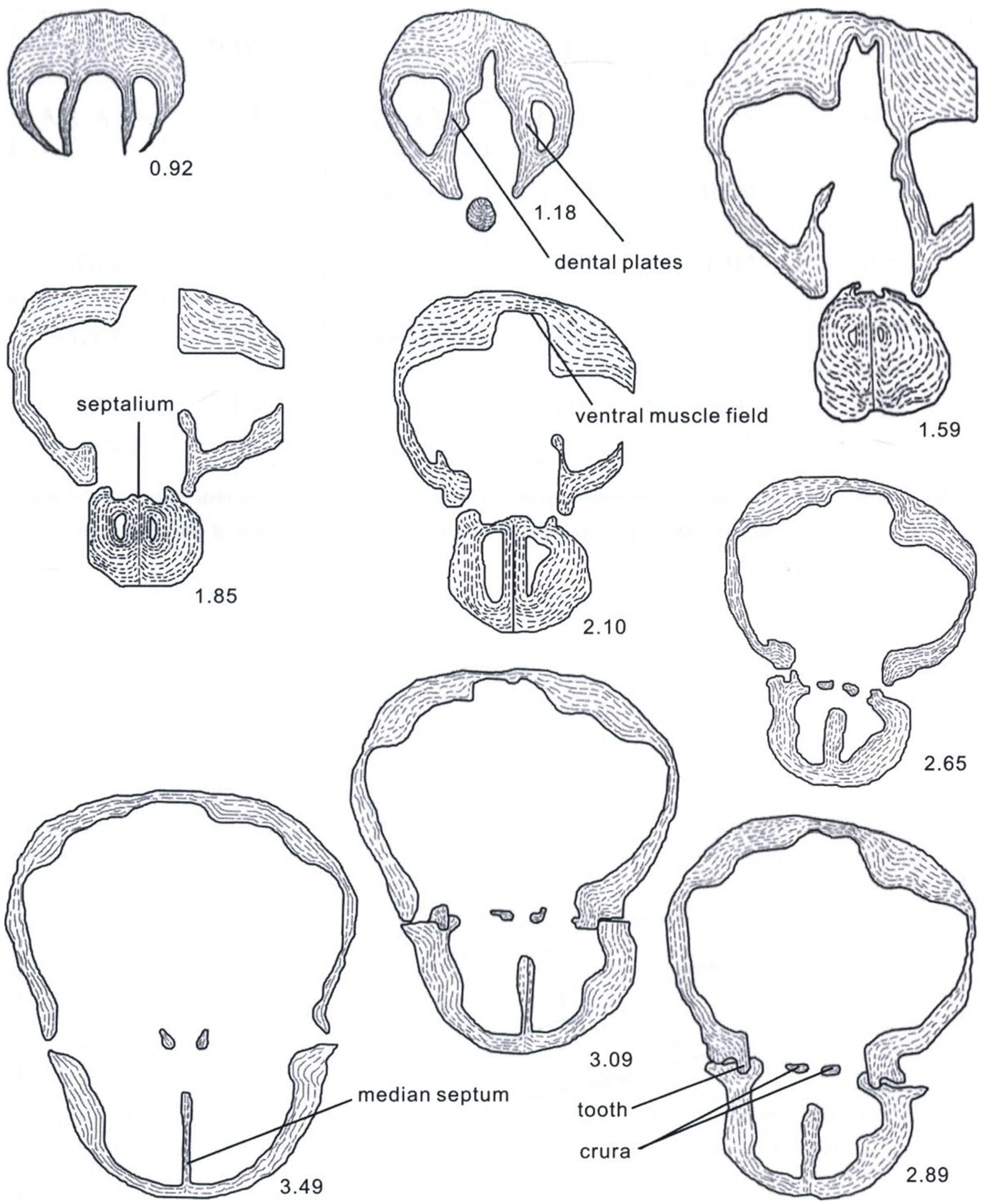


Fig. 2-20. Selected transverse serial sections of *Leiorhynchus laura* (Billings, 1860). W 2872. Rock Glen Submember, Petrolia Member, Widder Formation. Collecting locality 4. Distances in mm from posterior tip of ventral umbo. X6.0

	W	L	T	L/W	T/W
MEAN	21.11	24.32	14.71	1.15	0.70
STD	3.65	4.36	2.84	0.09	0.06
MIN	14.47	17.55	9.62	1.02	0.57
MAX	28.40	34.06	19.89	1.34	0.77
N	19	19	19	19	19

Table 2-14. Statistical data of shell dimensions (mm) for complete specimens of *Leiorhynchus laura* (Billings, 1860), sample from Collecting locality 4, Rock Glen Submember, Petrolia Member, Widder Formation.

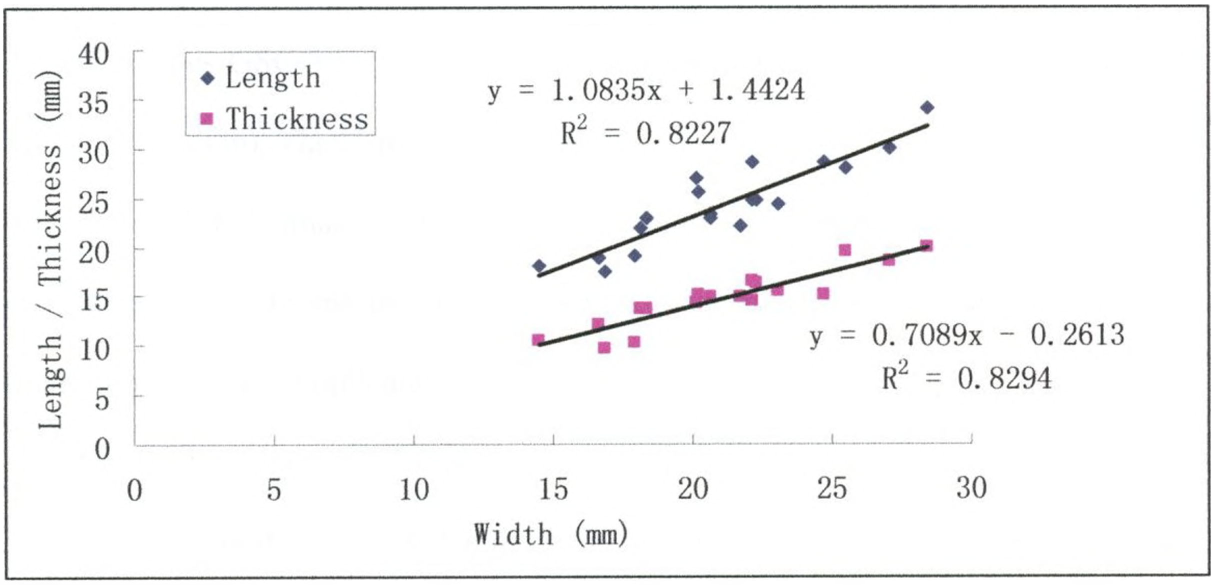


Fig. 2-21. Length-width and thickness-width graphs for complete specimens of *Leiorhynchus laura* (Billings, 1860), sample from Collecting locality 4, Rock Glen Submember, Petrolia Member, Widder Formation.

Superfamily STENOSCISMATOIDEA Oehlert, 1887a

Family STENOSCISMATIDAE Oehlert, 1887a

Subfamily STENOSCISMATINAE Oehlert, 1887a

Genus *Stenoscisma* Conrad, 1839

Type species: *Terebratula schlottheimii* von Buch, 1834, Germany (exact horizon and locality unknown, middle Upper Permian ?).

Stenoscisma kernahani (Whiteaves, 1898)

Pl. 2-9, figs. 16-20; Table 2-15; Fig. 2-22

1898 *Pugnax kernahani* Whiteaves, p. 387-388, fig. 3a-c.

1902 *Pugnax kernahani*; Shimer & Grabau, p. 182.

1942 *Camarophoria kernahani* (Whiteaves); Stumm, p. 562, pl. 84, figs. 25-27.

1944 *Stenoscisma kernahani* (Whiteaves); Shimer & Shrock, p. 315, pl. 120, figs. 46-48.

1958 *Stenoscisma kernahani* (Whiteaves); Stumm & Wright, p. 108.

Types. Syntypes GSC 3777, a-d, exact locality and horizon unknown, Hamilton Group (Middle Devonian), Thedford, Ontario.

Description. Shell small, moderately dorsibiconvex, subpentagonal; costae strong, rounded, simple, present on anterior region; maximum width at about mid-length; anterior commissure uniplicate.

Ventral valve regularly convex in the umbonal region; ventral sulcus shallow, commencing at mid-length, widening anteriorly; two costae present in sulcus; ventral interarea very low, apsacline; beak acute, small, slightly incurved.

Ventral interior with weak muscle marks in spondylium.

	W	L	T	L/W	T/W
MEAN	5.94	6.28	4.02	1.07	0.70
STD	1.18	0.89	1.13	0.09	0.09
MIN	4.36	5.17	2.85	0.99	0.60
MAX	7.10	7.26	5.53	1.19	0.78
N	5	5	4	5	4

Table 2-15. Statistical data of shell dimensions (mm) for better-preserved specimens of *Stenoscisma kernahani* (Whiteaves, 1898), sample from Collecting locality 1, Coral Unit, Hungry Hollow Member, Widder Formation.

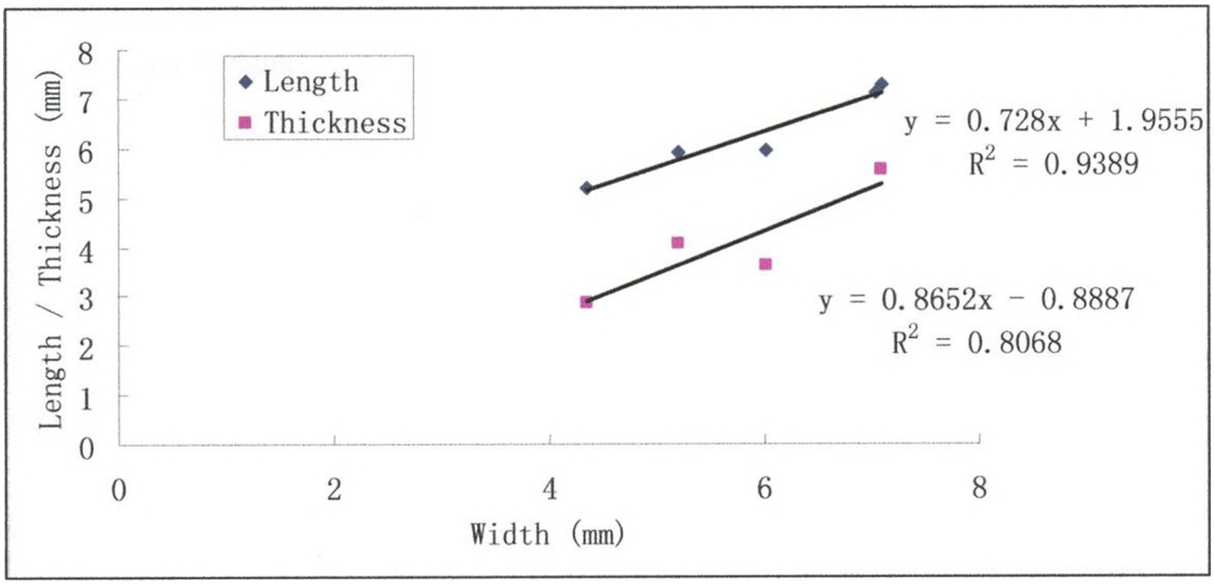


Fig. 2-22. Length-width and thickness-width graphs for better-preserved specimens of *Stenoscisma kernahani* (Whiteaves, 1898), sample from Collecting locality 1, Coral Unit, Hungry Hollow Member, Widder Formation.

Dorsal valve more convex than ventral valve; dorsal fold longitudinally depressed in the middle and bounded on each side by a short longitudinal groove; 2-3 costae present at the anterior region of fold.

Dorsal interior with elongate cruralium and thin, long crura.

Material. Total 9 incomplete specimens.

Occurrence. Coral Unit, Hungry Hollow Member, Widder Formation; Arkona-Thedford-Ipperwash area, southwestern Ontario.

Discussion. Stenoscisma illinoisensis (Cooper, 1945) from the Middle Devonian rocks of Illinois (Cooper, 1945, p. 484-485, pl. 63, figs. 13-17) is distinguishable from *S. kernahani* (Whiteaves, 1898) by its relatively transverse outline (width slightly greater than length) and prominent rounded costae (four on the fold and three in the sulcus). *S. halli* Fagerstrom, 1961 (Fagerstrom, 1961, p. 29, pl. 9, figs. 48-51) is somewhat similar in shape to *S. kernahani*, however, it differs from *S. kernahani* in its smaller size, lower ventral interarea, prominent rounded costae (two on the fold, one in the sulcus, and two or three on each flank).

Order ATRYPIDA Rzhonsnitskaia, 1960

Suborder ATRYPIDINA Moore, 1952

Superfamily ATRYPOIDEA Gill, 1871

Family ATRYPIDAE Gill, 1871

Subfamily ATRYPINAE Gill, 1871

Genus *Atrypa* Dalman, 1828

Type species: *Anomia reticularis* Linnaeus, 1758, lower Hemse beds (exact locality unknown), Early Gorstian, Ludlow, Silurian.

Atrypa (*Atrypa*) *reticularis* (Linnaeus, 1758)

Pl. 2-14, figs. 1-10; Table 2-16; Fig. 2-23; Fig. 2-24

1758 *Anomia reticularis* Linnaeus, p. 702.

1777 *Terebratula pectinata*, *T. subtillissime striatae*, *T. cancellata*, *T. minutissime striata*, Schroter, pl. iii, fig. 11-18, and pl. iv., fig. 16-26.

1822 *Terebratulites priscus* Schlotheim, p. xvii, fig. 2.

?1828 *Atrypa reticularis*; Dalman, p. 127-128, pl. 4, figs. 2a-e.

?1829 *Terebratula cancellata* Eichwald, p. 276, pl. 4, fig. 11.

1841 *Terebratula* (*Atrypa*) *prisca* Phillips, p. 81, pl. xxxiii, fig. 144.

1841 *Terebratula insperata* Phillips, p. 83, pl. xxxiii, fig. 18.

1848 *Terebratula reticularis*; Bronn, p. 1248.

1854 *Atrypa reticularis*; Morris, p. 132.

1858 *Atrypa reticularis*; Hall, p. 4-5, pl. vi.

1864 *Atrypa reticularis*; Davidson, pt. vi, p. 53.

1894b *Atrypa reticularis*; Hall and Clarke, p. 165, fig. 153; pl. 55, figs. 1-17.

1902 *Atrypa reticularis*; Shimer & Grabau, p. 153.

1915 *Atrypa reticularis*; Stauffer, p. 181.

1949 *Atrypa reticularis*; Alexander, pl. 9, figs. 1a-d.

1949 *Atrypa reticularis* var. *sedgwicki* Alexander, p. 215-216, pl. 10, figs. 5a-d.

1952 *Atrypa* cf. *Atrypa recticularis*; Kirk & Amsden, p. 63, pl. 8, figs. 8-17.

1958 *Atrypa reticularis*; Stumm & Wright, p. 105, 115, 121.

1961 *Atrypa* "*reticularis*"; Wright & Wright, p. 296.

1967 *Atrypa reticularis*; Brunton, Cocks, and Dance, p. 170-171, pl. 2, figs. 19-23.

1981 *Atrypa reticularis*; Savage, p. 366, pl. 2, figs. 8-11.

2004 *Atrypa* (*Atrypa*) *reticularis*; Copper, p. 37-39, pl. 2, figs. a-o; Fig. 12.

Types. Linnaeus's (1758) original description indicated neither a collecting locality, nor an exact type locality. Furthermore, Linnaeus did not illustrate any specimens. However, Linnaeus possibly acquired his lectotype specimen of *reticularis* from eastern shoreline outcrops on Gotland, at or near Hammaren, or an adjacent site in the lower Hemse beds, because these are the only exposed strata on that island (Copper, 2004). A specimen of *Atrypa* (*Atrypa*) (*reticularis*, 1758) from the lower Hemse beds (unit C, *scanicus* Zone, Gorstian, E coast Gotland, early Ludlow) was selected and illustrated as a lectotype by Copper (2004, p. 160, pl. 2, figs. a-e).

Description. Shell large, dorsibiconvex; suborbicular; shell covered with fine ribs (at the mid-length of shell, 5-7 in number per 5 mm) that bifurcate at or between concentric growth lines; hingeline short, approximately half maximum shell width; cardinal extremities rounded; anterior commissure uniplicate.

Ventral valve weakly convex; foramen transapical or obscured; sulcus shallow to inconspicuous.

Ventral interior with thick pedicle callist; anteriorly, small dental nuclei present; tooth prominent.

Dorsal valve strongly convex, rotund in the middle; dorsal fold inconspicuous; dorsal interarea linear.

Dorsal interior with strong cardinalia; cardinal process small; inner socket ridges bulbous, expanding into small crural bases; anteriorly, crura curved laterally into bushy crural fibres; jugal processes and spiralia not preserved in sectioned specimens (Figure 2-23).

Material. Total 245 complete specimens and 20 incomplete specimens.

Occurrence. Widder Formation; Ipperwash Limestone; Arkona-Thedford-Ipperwash area, southwestern Ontario.

Discussion. Atrypa reticularis inversa Savage, 1970 from the base of the Mandagery Park Formation (Lower Devonian) of New South Wales (Savage, 1970, P. 662-663, Pl. 103, figs. 1-39) differs from *Atrypa* (*Atrypa*) *reticularis* (Linnaeus, 1758) in its distinct ventral fold and dorsal sulcus, moderately curved ventral beak, obvious ventral interarea and coarser ribs. *Atrypa* cf. *A. pronis* Fenton & Fenton, 1935 from the Milwaukee Formation (Middle Devonian) of southeastern Wisconsin (Griesemer, 1965, p. 274, 276, pl. 4, figs. 9-11) is easily distinguished from *Atrypa* (*Atrypa*) *reticularis* by its subtriangular shape and strongly uniplicate anterior margin contrasting with the suborbicular shape and moderate uniplicate anterior margin of the latter. *A. penelopeae* Chatterton, 1973 from the Early-Middle Devonian Murrumbidgee Group, Taemas, New South Wales (Chatterton, 1973, p. 87, pl. 20, figs. 15-16; pl. 21, figs. 12-23,

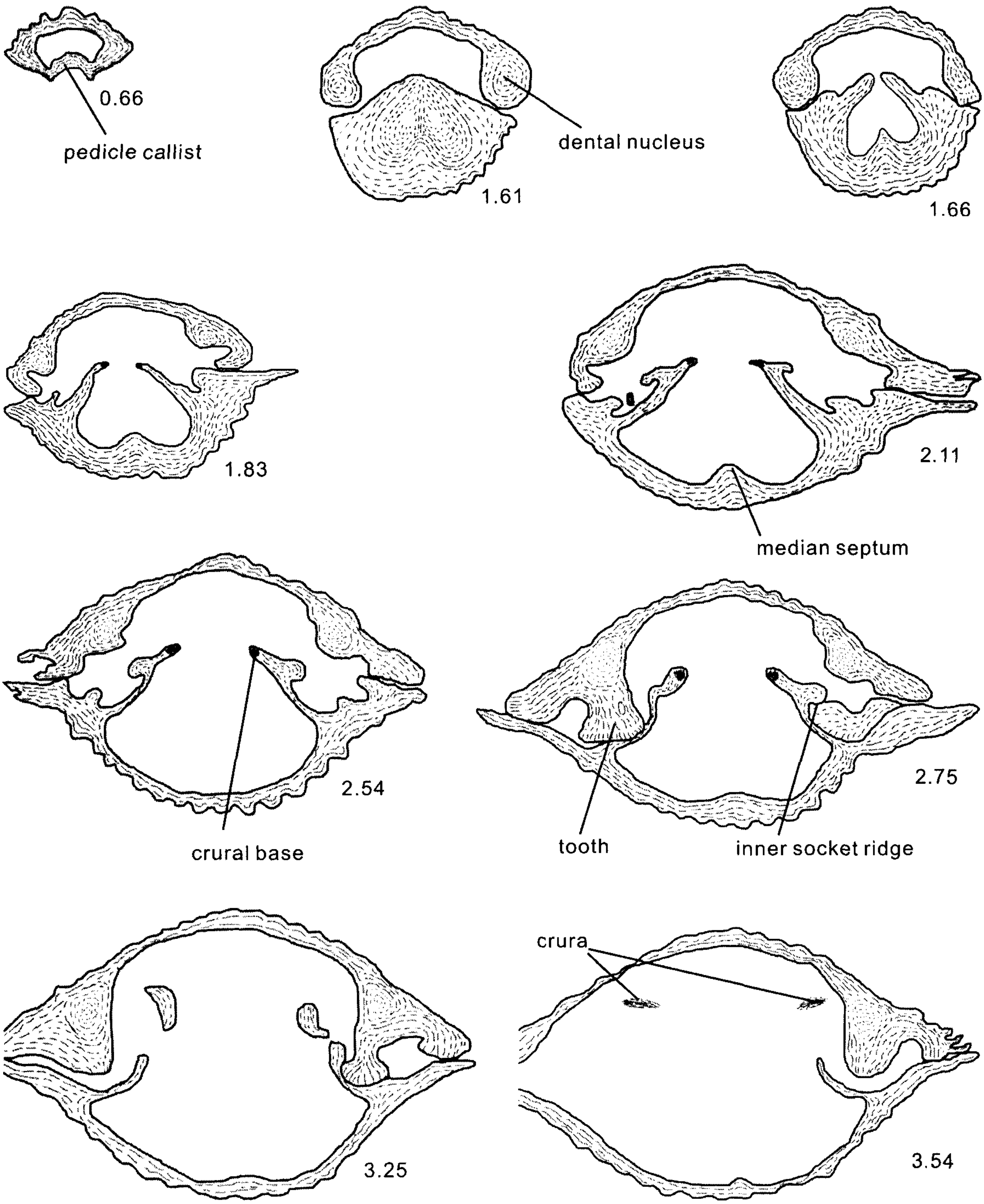


Fig. 2-23. Selected transverse serial sections of *Atrypa* (*Atrypa*) *reticularis* (Linnaeus, 1758). W 2854. Coral unit, Hungry Hollow Member, Widder Formation. Collecting locality 1. Distances in mm from posterior tip of ventral umbo. X6.5

	W	L	T	L/W	T/W
MEAN	16.27	16.12	6.90	0.99	0.43
STD	4.22	4.15	2.13	0.06	0.08
MIN	5.28	5.67	2.63	0.80	0.22
MAX	26.38	24.87	11.80	1.08	0.60
N	46	46	46	46	46

Table 2-16. Statistical data of shell dimensions (mm) for complete specimens of *Atrypa* (*Atrypa*) *reticularis* (Linnaeus, 1758), sample from Collecting locality 1, Hungry Hollow Member, Widder Formation.

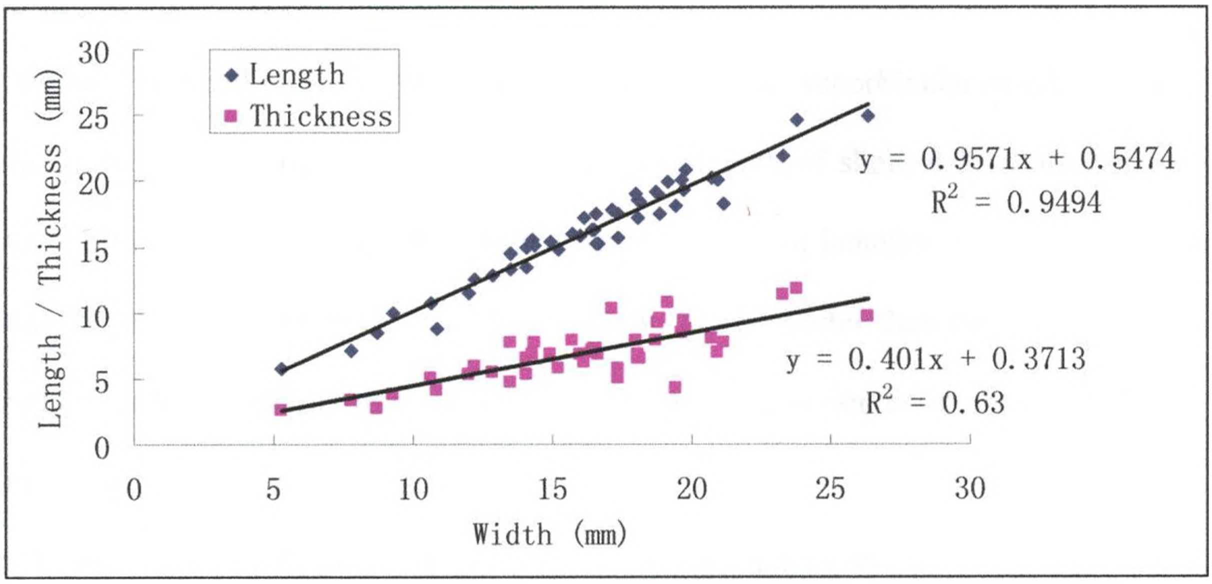


Fig. 2-24. Length-width and thickness-width graphs for complete specimens of *Atrypa* (*Atrypa*) *reticularis* (Linnaeus, 1758), sample from Collecting locality 1, Hungry Hollow Member, Widder Formation.

figs. 25-29; pl. 22, figs. 1-10; text-figs. 29-30) is distinguished from *Atrypa* (*Atrypa*) *reticularis* by having wider outline and coarser, fewer ribs on the surface of the valves.

Subfamily VARIATRYPINAE Copper, 1978

Genus *Pseudoatrypa* Copper, 1973

Type species: *Atrypa devoniana* Webster, 1921, Hackberry Group (Frasnian, Upper Devonian), Iowa.

Pseudoatrypa cf. *devoniana* (Webster, 1921)

Pl. 2-14, figs. 11-15; Table 2-17; Fig. 2-25; Fig. 2-26

Types. Lectotype of *Pseudoatrypa devoniana* (Webster, 1921), USNM 84666, selected by Copper (1973, p. 492, pl. 1. figs. 3-6), from the Cerro Gordo Member (*Cyrtospirifer whitneyi* zone), Lime Creek Formation, Hackberry Group (Frasnian, Upper Devonian), Rockford, Iowa, U.S.A..

Description. Shell large, dorsibiconvex to convexoplane, suborbicular to subrectangular; shell covered with fine tubular ribs (at the mid-length of shell, 4-5 in number per 5 mm), bifurcate at the concentric growth lamellae; growth lamellae crowded anteriorly, with no frills or short frills; hingeline straight, much shorter than the maximum shell width; cardinal extremities rounded to right-angled; anterior commissure moderately uniplicate.

Ventral valve weakly convex to weakly resupinate anteriorly; ventral interarea small, anacline to hypercline; foramen commonly large, apical to transapical; deltidial plates small or lost in adult specimens; sulcus shallow to inconspicuous;

Ventral interior with reduced dental cavities; no pedicle callist present in ventral valve; teeth relatively small.

Dorsal valve strongly convex; fold inconspicuous; dorsal interarea undeveloped.

Dorsal interior with delicate hinge plates; anteriorly, crura bushy, feathered; jugal processes disjunct; spiralia obvious, with 6-8 whorls (Figure 2-25).

Material. Total 80 complete specimens and 13 incomplete specimens.

Occurrence. Widder Formation; Ipperwash Limestone; Arkona-Thedford-Ipperwash area, southwestern Ontario.

Discussion. Although *Pseudoatrypa* cf. *devoniana* (Webster, 1921) is similar to *P. devoniana* (Webster, 1921) in terms of both external and internal characters, the spiralia in the latter species contains a greater number of whorls (8-12 in number) (Copper, 1973, p. 492). Furthermore, *P. devoniana* is only restricted to the late Frasnian (Day & Copper, 1998, p. 164) while *P.* cf. *devoniana* in the study area is from Givetian age. *P. godefroidi* Mottequin, 2008 from the late Middle to Late Frasnian (*Palmatolepis hassi* to Upper *P. rhenana* zones) rocks in the Namur–Dinant Basin of southern Belgium (Mottequin, 2008, p. 498, figs. 3. 14-28, 4 and 5) is distinguishable from *P.* cf. *devoniana* (Table 2-17) in its smaller size (average width of 23. 98 mm and average length of 19.95 mm), smaller length to width ratio (L/W= 0.83), and coarser ribs. *P. witzkei* Day & Copper, 1998 (Day & Copper, 1998, p. 172, figs. 15-17) from the middle Frasnian Shell Rock Formation of north-central Iowa is distinguished from *P.* cf. *devoniana* by its more convex ventral valve and lower tongue.

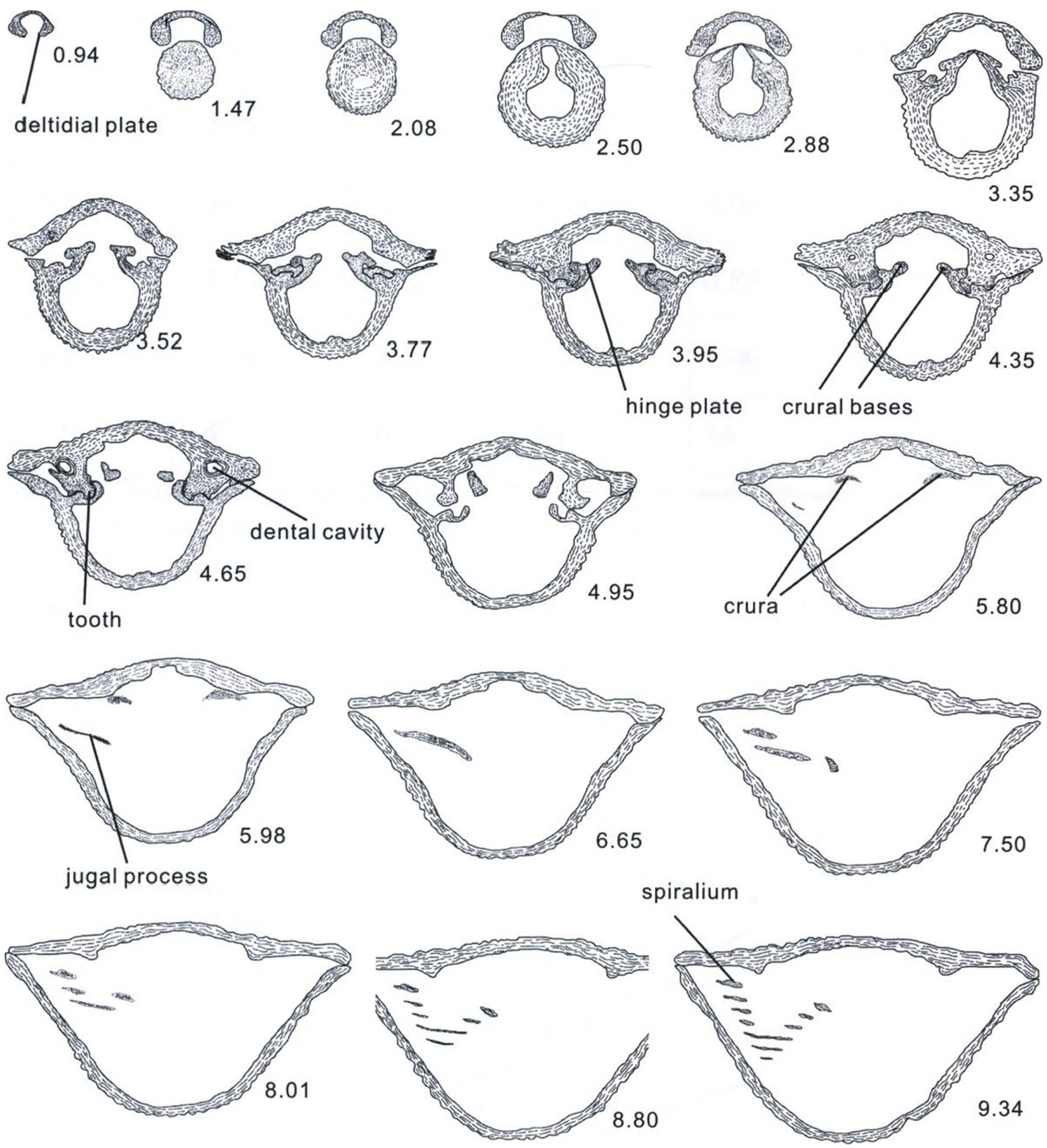


Fig. 2-25. Selected transverse serial sections of *Pseudoatrypa* cf. *devoniana* (Webster, 1921). W 2861. Ipperwash Limestone. Collecting locality 9. Distances in mm from posterior tip of ventral umbo. X2.0

	W	L	T	L/W	T/W
MEAN	24.15	23.17	12.68	0.96	0.52
STD	4.64	4.52	3.33	0.05	0.07
MIN	15.13	13.82	7.08	0.85	0.37
MAX	35.84	36.58	23.63	1.06	0.66
N	36	36	36	36	36

Table 2-17. Statistical data of shell dimensions (mm) for complete specimens of *Pseudoatrypa* cf. *devoniana* (Webster, 1921), sample from Collecting locality 9, Ipperwash Limestone.

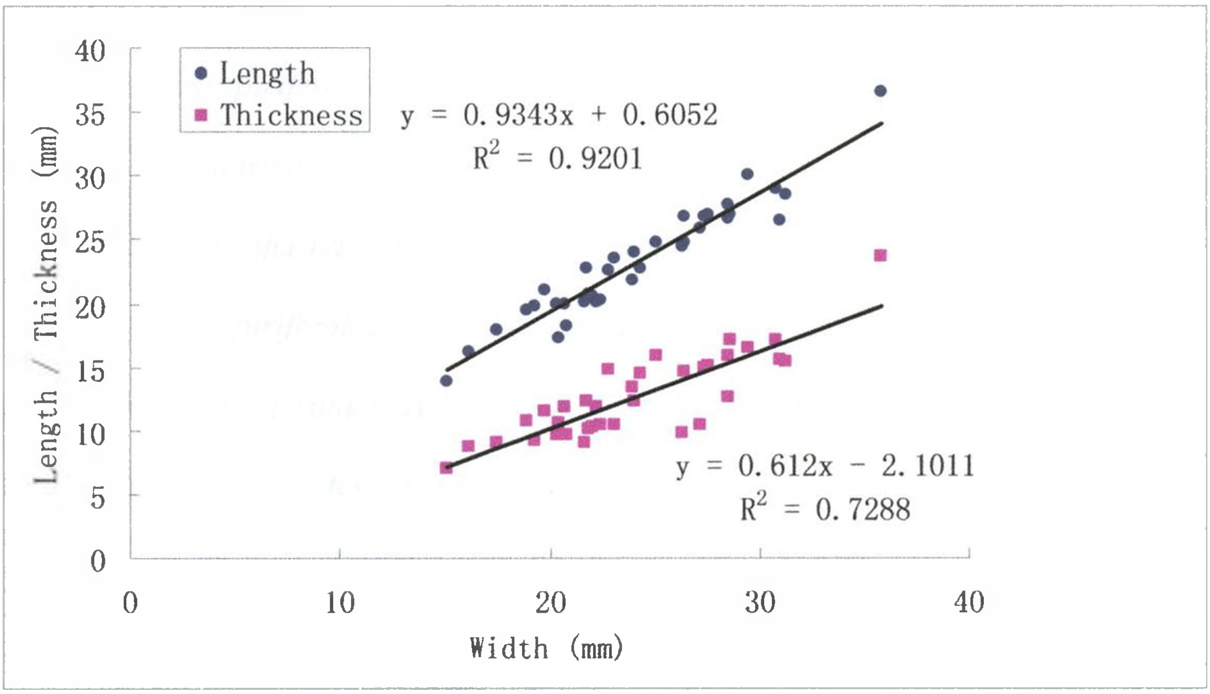


Fig. 2-26. Length-width and thickness-width graphs for complete specimens of *Pseudoatrypa* cf. *devoniana* (Webster, 1921), sample from Collecting locality 9, Ipperwash Limestone.

Order ATHYRIDIDA Boucot, Johnson and Staton, 1964b

Suborder ATHYRIDIDINA Boucot, Johnson and Staton, 1964b

Superfamily ATHYRIDOIDEA Davidson, 1881

Family ATHYRIDIDAE Davidson, 1881

Subfamily ATHYRIDINAE Davidson, 1881

Genus *Athyris* M'Coy, 1844

Type species: *Terebratula concentrica* von Buch, 1834, Eifel (exact horizon and locality unknown, Eifelian, Middle Devonian), Germany.

Athyris spiriferoides (Eaton, 1832)

Pl. 2-12, figs. 6-20 ; Table 2-18 ; Fig. 2-27 ; Fig. 2-28

1832a *Terebratula spiriferoides* Eaton, p. 137.

1832b *Terebratula spiriferoides* Eaton, p. 46.

1838 *Atrypa concentrica* Conrad, p. 111.

1857 *Spirifera spiriferoides*; Hall, p. 153, figs. 1-2.

1860b *Athyris spiriferoides*; Hall, p. 93, figs. 1-4.

1867 *Athyris spiriferoides*; Hall, p. 285, pl. 46, figs. 5-31.

1889 *Spirigera spiriferoides*; Whiteaves, p. 124.

1894b *Athyris spiriferoides*; Hall and Clarke, p. 89, figs. 60-61; pl. 45, figs. 11-27.

1915 *Athyris spiriferoides*; Stauffer, P. 171.

1958 *Athyris spiriferoides*; Stumm & Wright, p. 105, 115, 120.

1969 *Athyris spiriferoides*; Buehler, p. 1291, text-fig. 1.

Types. Eaton (1832a) indicated that the specimens upon his diagnosis of the species was based from "coral rags" (probably Givetian age), near Eighteen- Mile Creek on the south shore of Lake Erie, New York, but neither described nor illustrated the specimens themselves. Original types cannot be traced from previous references.

Description. Shell medium to large, biconvex, subpentagonal, transversely extended; surface of shell covered by irregular, thin and slightly lamellose growth lines; growth lines more frequently at the anterior area; hinge line short; cardinal extremities rounded; maximium width at mid-length.

Ventral valve moderately to strongly convex; sulcus shallow and narrow, commencing at ventral beak and widening anteriorly, oval foramen prominent, interarea low; anterior commissure uniplicate.

Ventral interior with dental plates; dental plates thin, short, subparallel; ventral muscle field weakly impressed; teeth stout and subrectangular.

Dorsal valve moderately to strongly convex; fold inconspicuous; dorsal interarea linear.

Dorsal interior with relatively thick and long jugal saddle; anteriorly, spiralia present (Figure 2-27).

Material. Total 320 complete specimens and 56 incomplete specimens.

Occurrence. Arkona Shale Formation; Widder Formation; Ipperwash Limestone; Arkona-Thedford-Ipperwash area, southwestern Ontario.

Discussion. Athyris spiriferoides (Eaton, 1832) can be distinguished from *A. cora* Hall, 1860 from the Middle Devonian Formosa Reef Limestone of southwestern Ontario (Fagerstrom, 1961, p. 34, pl. 10, fig. 27; pl. 11, figs. 37-41) by its better defined fold and sulcus, proportionally smaller convexity of ventral valve, and lower elevation of umbo. *A. spiriferoides* differs from *A. eborea* from the Middle Devonian Traverse

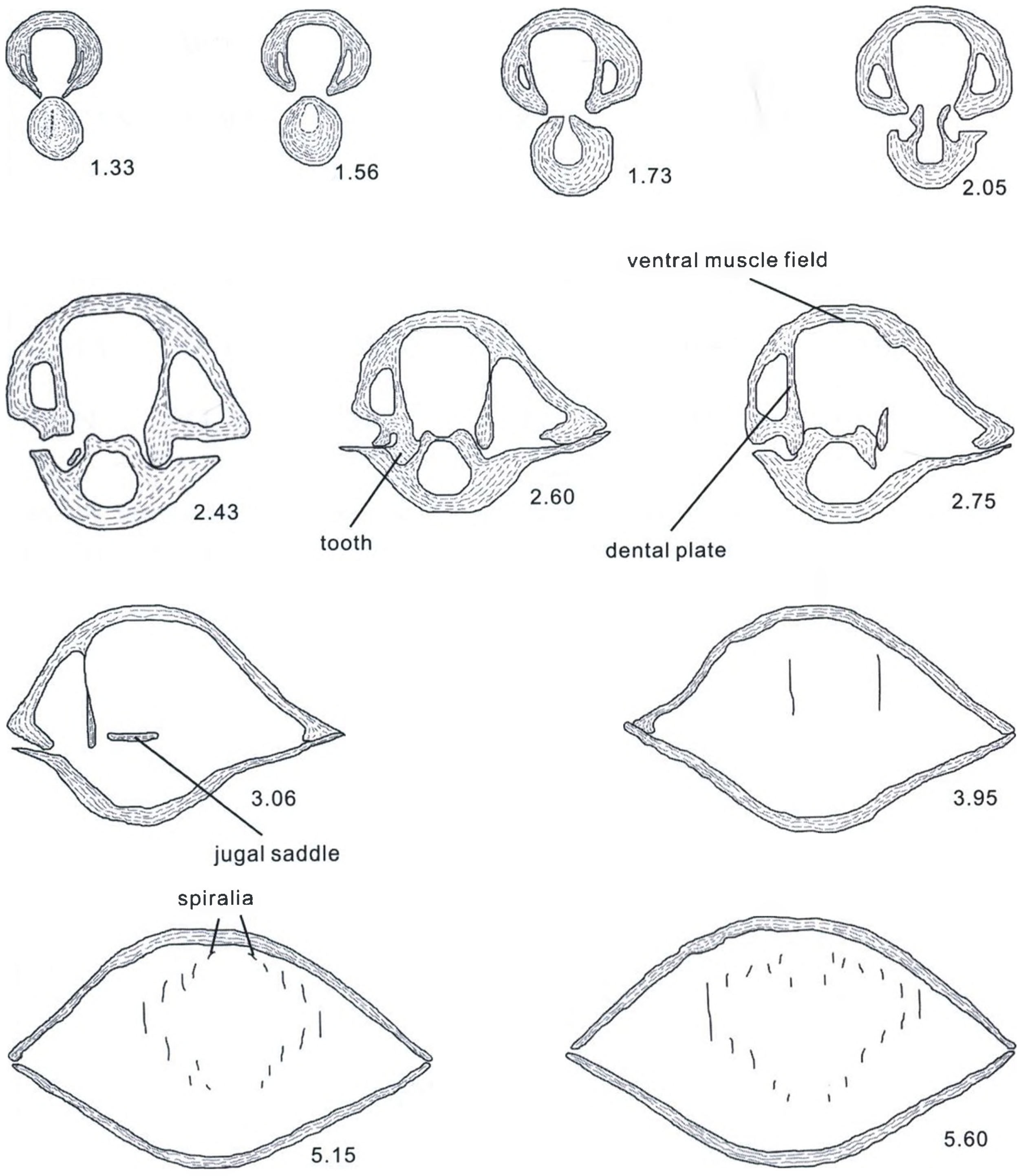


Fig. 2-27. Selected transverse serial sections of *Athyris spiriferoides* (Eaton, 1832). W 2852. Ipperwash Limestone. Collecting locality 9. Distances in mm from posterior tip of ventral umbo. x4.5

	W	L	T	L/W	T/W
MEAN	16.94	14.97	8.76	0.89	0.52
STD	3.92	3.20	2.15	0.04	0.05
MIN	9.82	9.41	5.64	0.79	0.42
MAX	26.18	21.28	13.85	0.97	0.65
N	33	33	33	33	33

Table 2-18. Statistical data of shell dimensions (mm) for complete specimens of *Athyris spiriferoides* (Eaton, 1832), sample from Collecting locality 4, Rock Glen Submember, Petrolia Member, Widder Formation.

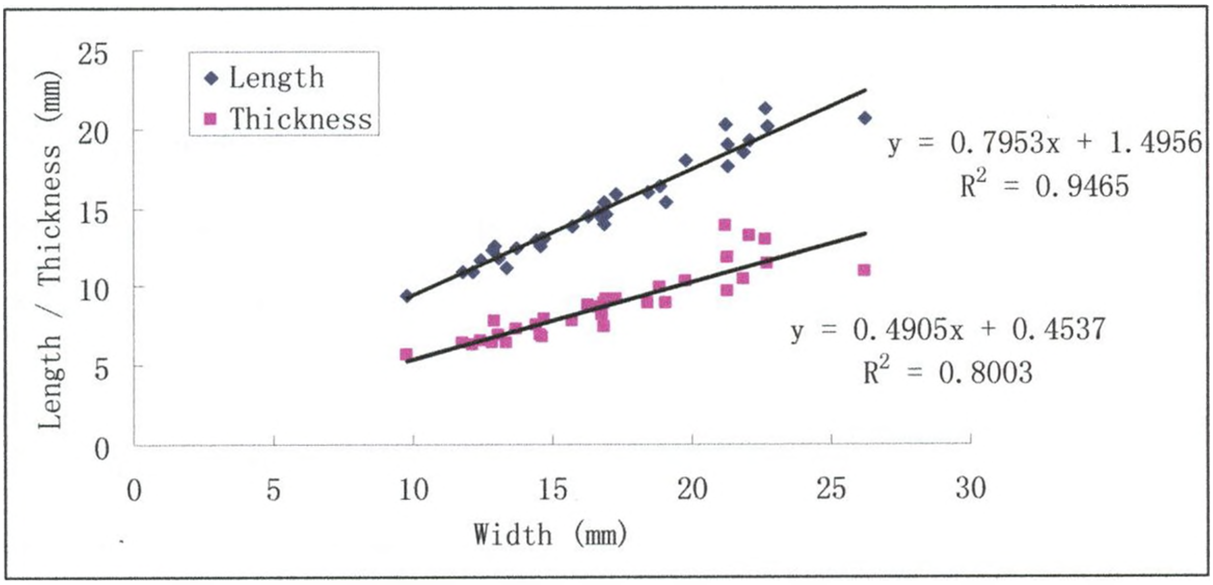


Fig. 2-28. Length-width and thickness-width graphs for complete specimens of *Athyris spiriferoides* (Eaton, 1832), sample from Collecting locality 4, Rock Glen Submember, Petrolia Member, Widder Formation.

Group of Michigan (Winchell, 1866) (Ehlers and Kline, 1934, p. 163-164, pl. 4, figs. 1-6) in larger size, higher fold and deeper sulcus, more prominent lamellose growth lines, and proportional smaller convexity of the ventral valve. *A. lens* (Winchell, 1866) (Ehlers and Kline, 1934, p. 165-166, pl. 4, figs. 7-11) is distinguished from *A. spiriferoides* by its subcircular outline and less pronounced fold and sulcus. Although *A. aquilonius* Norris, 1964 from the lower thin-bedded unit of the Middle Devonian Horn Plateau Formation, district of Mackenzie (McLaren and Norris, 1964, p. 62-63, pl. 17, figs. 4a-10) resembles *A. spiriferoides*, it differs in having less alate appearance, general smaller size, proportionate thicker lateral profile, more steeply sloping hing line, more pronounced fold and sulcus, and weaker growth lamellae (McLaren and Norris, 1964, p. 63).

Athyris vittata Hall, 1860

Pl. 2-12, figs. 1-5; Table 2-19; Fig. 2-29; Fig. 2-30

1860b *Athyris vittata* Hall, p. 89.

1867 *Athyris vittata*; Hall, p. 289, pl. 46, figs. 1-4.

1897 *Athyris fultonensis* Schuchert, p. 147.

1915 *Athyris vittata*; Stauffer, p. 115.

1923 *Athyris vittata*; Savage, p. 556.

1936 *Athyris vittata*; Laudon, p. 61.

1958 *Athyris vittata*; Stumm & Wright, p. 91, 105, 115.

1998 *Athyris vittata*; Day & Copper, p. 176.

Types. Hall (1860b) based the original description of this species on specimens from strata of the Middle Devonian Hamilton Group, near Iowa city. He did not illustrate any specimens or designate a holotype. Original types cannot be traced from previous references.

Description. Shell medium, biconvex, subpentagonal; surface of shell covered by numerous, thin and slightly lamellose growth lines; growth lines more frequent at anterior area of shell; hinge line short; cardinal extremities rounded; maximium width at mid-length.

Ventral valve moderately to strongly convex; sulcus well-defined, commencing at ventral beak, widening anteriorly; oval foramen prominent; umbone located approximately 2-3 mm above the hinge line; interarea moderately high; anterior commissure uniplicate.

Interior of ventral valve with dental plates; dental plates subparallel, thin, short, slightly concave; teeth stout and subrectangular; ventral muscle field irregular and moderately impressed.

Dorsal valve moderately to strongly convex; fold relatively high and rounded, beginning at mid-length of shell; dorsal interarea linear.

Dorsal interior with prominent inner socket ridges; jugal saddle narrow and short; anteriorly, spiralia present (Figure 2-29).

Material. Total 61 complete specimens and 13 incomplete specimens.

Occurrence. Arkona Shale Formation; Widder Formation; Ipperwash Limestone; Arkona-Thedford-Ipperwash area, southwestern Ontario.

Discussion. Athyris vittata Hall, 1860 is distinguishable from *Athyris spiriferoides*

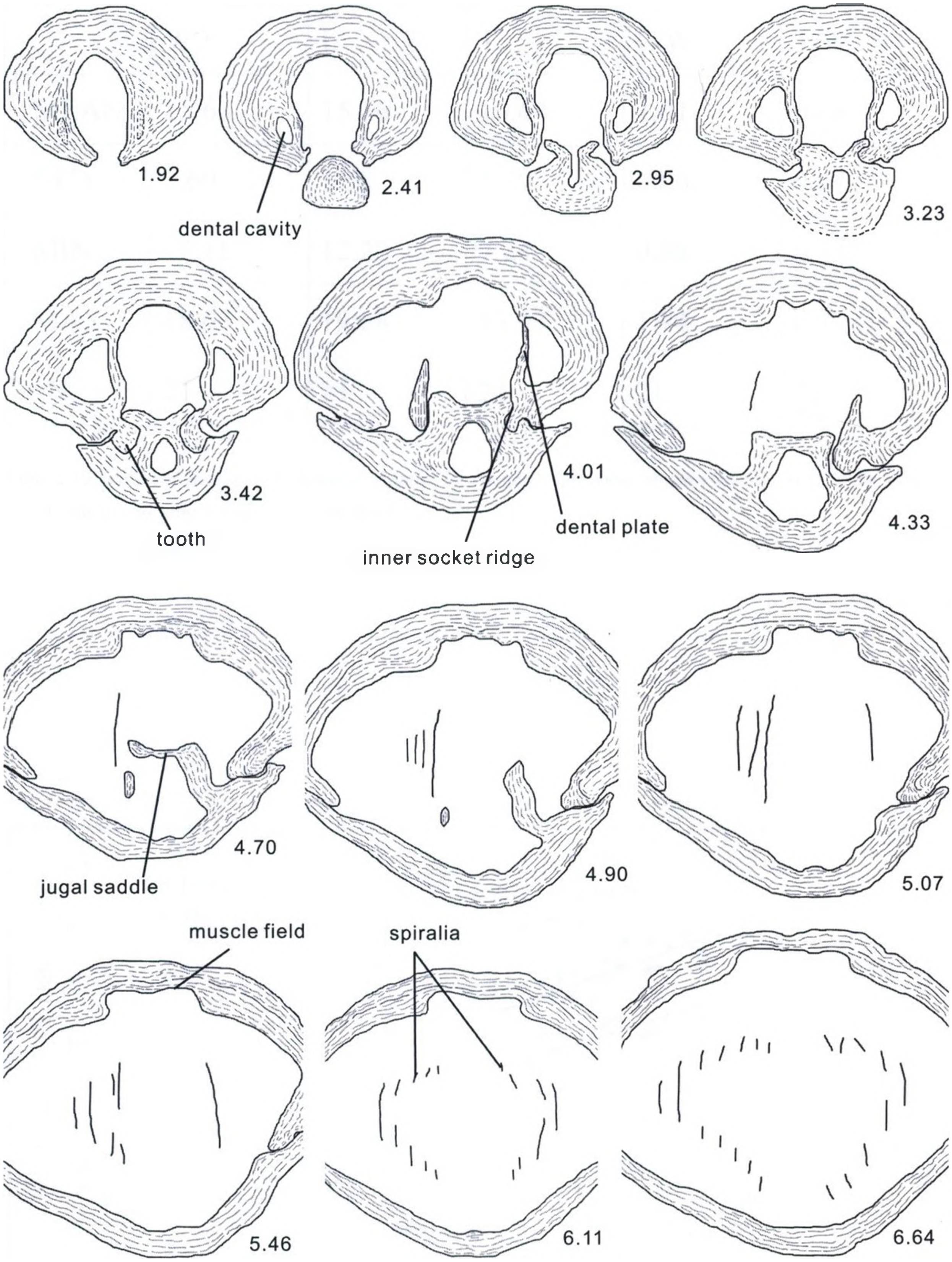


Fig. 2-29. Selected transverse serial sections of *Athyris vittata* Hall, 1860. W 2850. Thedford Member, Widder Formation. Collecting locality 3. Distances in mm from posterior tip of ventral umbo. X4.5

	W	L	T	L/W	T/W
MEAN	15.63	15.76	10.64	1.01	0.68
STD	1.69	1.90	1.79	0.06	0.07
MIN	12.11	12.22	7.24	0.88	0.53
MAX	18.63	19.08	13.97	1.14	0.79
N	21	21	21	21	21

Table 2-19. Statistical data of shell dimensions (mm) for complete specimens of *Athyris vittata* Hall, 1860, sample from Collecting locality 9, Ipperwash Limestone.

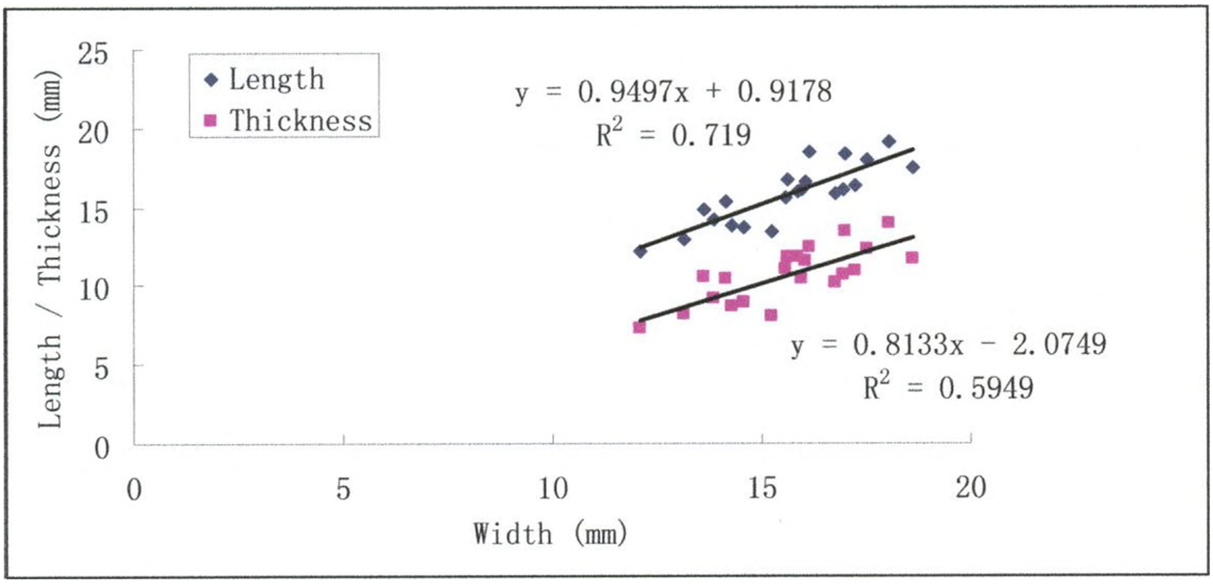


Fig. 2-30. Length-width and thickness-width graphs for complete specimens of *Athyris vittata* Hall, 1860, sample from Collecting locality 9, Ipperwash Limestone.

(Eaton, 1831) by its gibbous shape. Both length/width and thickness/width ratios in *A. vittata* are greater than those in *A. spiriferoides*. With respect to the interior characters, James Hall (1867) indicated that the character of spires of *A. vittata*, in their first volution and in the accessary lamella, differs from that of *A. spiriferoides*. Jugal saddle of *A. vittata* is narrower and shorter than that of *A. spiriferoides*. In addition, shell wall of *A. vittata* is much thicker than that of *A. spiriferoides* and the ventral muscle field of *A. vittata* is more concave. Although *A. vittata* is related to *A. sesquiplicata* (Winchell, 1866) from the Middle Devonian Traverse Group of Michigan (Ehlers and Kline, 1934, p. 166-168, pl. 4, figs. 12-23), the former is larger and its growth lines are more lamellose, and has a relatively higher fold and more prominent sulcus. *A. nuculoidea* Cooper, 1945 from the Middle Devonian rocks of Illinois (Cooper, 1945, p. 485486, pl. 64, figs. 12-19) resembles *A. vittata* Hall, 1867 in external features; however, the former species is distinguished by its smaller size, deeper sulcus (which originates near the mid-length of the shell), and relatively higher fold that clearly defines about one-third the length. Although *A. vittata randalia* Stainbrook, 1942 from the Middle Devonian Milwaukee Formation of southeastern Wisconsin (Griesemer, 1965, p. 286, 288, pl. 6, figs. 1-6) is somewhat similar in shape to *Athyris vittata*, the former is smaller in size (average width: 10.4 mm, average length: 10.1 mm, average thickness: 6.3 mm), has smaller length/width and thickness/width ratios (0.97 and 0.61 respectively), and a stronger fold.

Superfamily MERISTELLOIDEA Waagen, 1883

Family MERISTELLIDAE Waagen, 1883

Subfamily MERISTELLINAE Waagen, 1883

Genus *Charionella* Billings, 1861

Type species: *Atrypa scitula* Hall, 1843, Onondaga Limestone (Middle Devonian), Cayuga, Ontario, Canada.

Charionella scitula (Hall, 1843)

Pl. 2-15, figs. 16-20; Table 2-20; Fig. 2-31; Fig. 2-32

1843 *Atrypa scitula* Hall, p. 171, fig. 67. 1.

1860 *Athyris* ? *scitula*; Billings, p. 278, figs. 35-38.

1867 *Meristella scitula*; Hall, p. 302, pl. 47, figs. 34-38.

1894b *Charionella scitula*; Hall & Clarke, p. 78, pl. 42, figs. 17-19.

1965 *Charionella scitula*; Boucot, Johnson & Station, p. 656, fig. 533.3c.

1994 *Charionella scitula*; Linsley, pl. 91, figs. 18-19.

2000 *Charionella scitula*; Alvarez & Brime, p. 4, figs. 1.6-1.10.

Types. Lectotype I1215, the Corniferous Limestone (Middle Devonian), Williamsville and Clarence-hollow, Erie County, New York.

Description. Shell small to medium, ovate to subtrigonal, longer than wide, biconvex; maximium width located at about 3/5 of the shell length from the ventral umbo; surface of shell covered by numerous fine concentric growth lines; anterior margin broadly rounded; anterior commissure rectimarginate.

Ventral valve relatively strongly convex, with the greatest depth slightly posterior to the mid-length of the shell, oval foramen prominent; ventral sulcus ill-defined.

Ventral interior with pedicle callist; dental plates short; ventral median septum absent; teeth small.

Dorsal valve moderately convex, with greatest depth posterior to the middle; dorsal fold inconspicuous.

Dorsal interior with deep septalium (Figure 2-31).

Material. Total 35 complete specimens and 16 incomplete specimens.

Occurrence. Hungry Hollow Member, Widder Formation; Arkona-Thedford-Ipperwash area, southwestern Ontario.

Discussion. Charionella ? nortoni Stainbrook 1942 from the Upper Devonian Cedar Valley Limestone of Iowa, U.S.A. (Stainbrook, 1942, p. 619, pl. 89, figs. 39-42, text-fig. 4) differs from *C. scitula* (Hall, 1843) (Table 2-20) in its larger length/width and thickness/width ratios (the holotype M.A.S. 302 : L/W: 1.49, T/W: 0.80; the paratype M.A.S. 303: L/W: 1.48, T/W: 0.82, note: M.A.S. are the initials of author Merrill A. Stainbrook), deeper, subangular ventral sulcus and stronger development of septa in its dorsal valve.

Genus *Pentagonia* Cozzens, 1846

Type species: *Atrypa uniangulata* Hall, 1861, Helderberg Group (Lower Devonian), New York.

Pentagonia bisulcata (Cooper) ?

Pl. 2-16, figs. 16-20

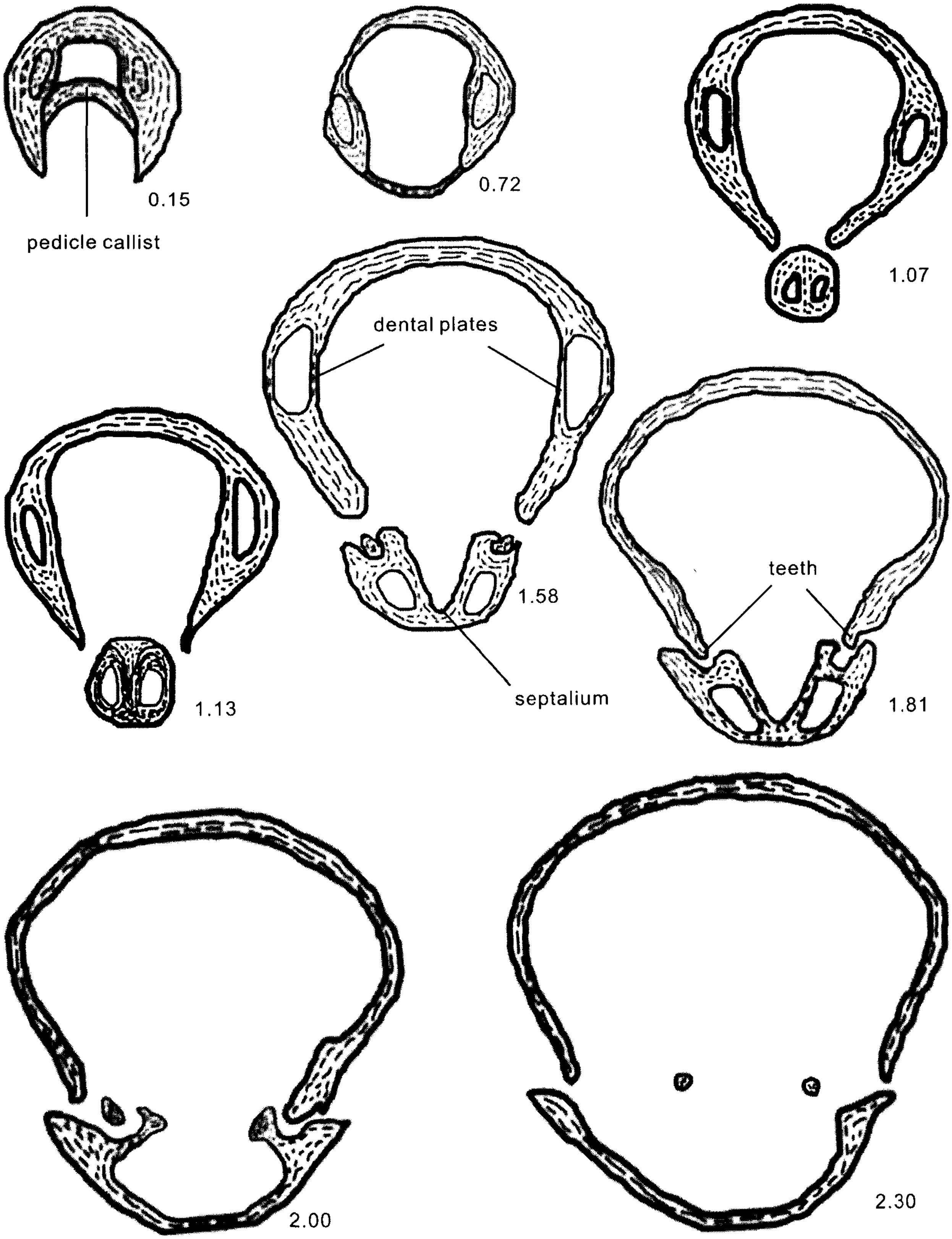


Fig. 2-31. Selected transverse serial sections of *Charionella scitula* (Hall, 1843). W 2922. Coral Unit, Hungry Hollow Member, Widder Formation. Collecting locality 3. Distances in mm from posterior tip of ventral umbo. X14.0

	W	L	T	L/W	T/W
MEAN	10.28	11.41	5.99	1.11	0.59
STD	2.57	2.75	1.45	0.05	0.05
MIN	6.83	8.04	4.34	1.03	0.48
MAX	15.16	15.97	9.66	1.19	0.65
N	13	13	13	13	13

Table 2-20. Statistical data of shell dimensions (mm) for complete specimens of *Charionella scitula* (Hall, 1843), sample from Collecting locality 5, Coral Unit, Hungry Hollow Member, Widder Formation.

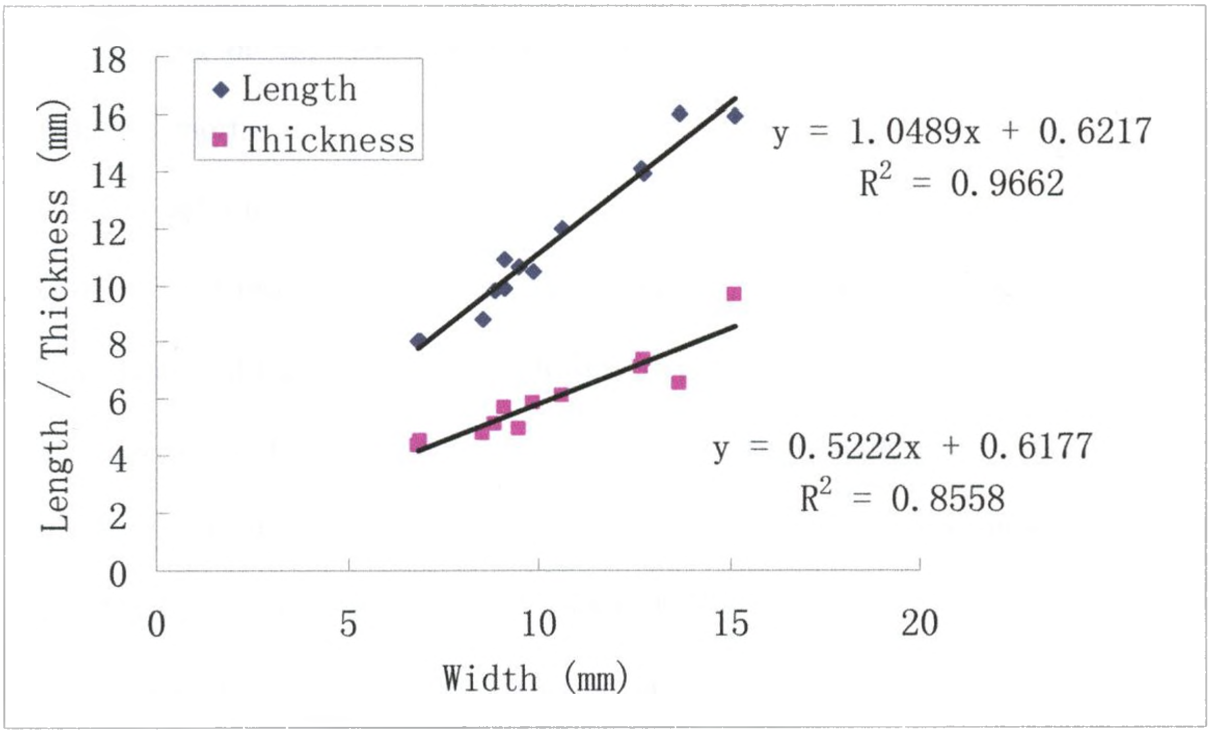


Fig. 2-32. Length-width and thickness-width graphs for complete specimens of *Charionella scitula* (Hall, 1843), sample from Collecting locality 5, Coral Unit, Hungry Hollow Member, Widder Formation.

1944 *Pentagonia bisulcata* (Cooper); Shimer and Shrock, p. 333, pl. 127, figs. 32, 36.

Types. Original types cannot be traced from previous references.

Description. Shell large, dorsibiconvex, pentagonal; surface of shell covered by numerous, thin and weak growth lines; maximium width at mid-length of shell; anterior commissure uniplicate.

Ventral moderately convex; sulcus shallow and very broad, bounded by angular divergent carinae; lateral slopes abrupt.

Ventral interior with short dental plates; ventral muscle field flaring widely laterally.

Dorsal valve more convex than ventral valve; fold broad and strong, with narrow medial groove; two shorter and narrow folds present on the posterolateral region.

Dorsal interior with ponderous thickened hinge plates extending vertically from the bottom of the dorsal valve, presenting an erect and concave anterior face; crural bases elongate, lying on the lateral portions of the upper face of the anterior wall; crura straight and short.

Material. Total 6 incomplete specimens.

Occurrence. Coral Unit, Hungry Hollow Member, Widder Formation; Arkona-Thedford-Ipperwash area, southwestern Ontario.

Discussion. These 6 incomplete specimens are externally quite similar to *Pentagonia bisulcata* (Cooper) figured by Shimer and Shrock (1944), who also mentioned that *P. bisulcata* came from the Centerfield Member (Ludlowville Formation, Hamilton Group) of New York State and equivalent strata in Ontario, Hungry Hollow Formation (now Hungry Hollow Member), where these 6 specimens were from. Thus, it is quite possible that these 6 specimens belong to *P. bisulcata*. They were tentatively assigned to this species in this thesis. However, it needs to be mentioned that, due to the lack of study on original types of this species, these 6 incomplete specimens could not be certainly assigned to *P. bisulcata*. The further certain identification needs more complete specimens and comparison with the original types. *Pentagonia unisulcata* (Conrad, 1841) from Lower Devonian rocks of Orange County, New York (Boucot, 1959b, p. 748-749, pl. 94, figs. 9-10) differs from these 6 specimens in having subcircular outline, a narrower fold and a deeper, longer median depression on the fold.

Superfamily NUCLEOSPIROIDEA Davidson, 1881

Family NUCLEOSPIRIDAE Davidson, 1881

GENUS *Nucleospira* Hall, in Davidson, 1858

Type species: *Spirifer ventricosus* Hall, 1857, Lower Helderberg Limestone (Lower Devonian), Albany County, New York.

Nucleospira concinna (Hall, 1843)

Pl. 2-13, figs. 6-20; Table 2-21; Fig. 2-33; Fig. 2-34

1843 *Atrypa concinna* Hall, p.200, fig. 80. 3.

1852 *Orthis concinna*; Hall, p. 200.

1859 *Nucleospira concinna*; Hall, p. 25, and 26.

1867 *Nucleospira concinna*; Hall, p. 279, pl. 45, figs. 33-57.

1882 *Nucleospira concinna*; Davidson, p. 121.

1884 *Nucleospira concinna*; Walcott, p. 147.

1889 *Nucleospira concinna*; Nettelroth, p. 103, pl. 32, figs. 1-4.

1894b *Nucleospira concinna*; Hall & Clarke, p. 145, fig. 131; pl. 48, figs. 12-17, 19-34; pl. 84, fig. 38.

1902 *Nucleospira concinna*; Shimer & Grabau, p. 153.

1915 *Nucleospira concinna*; Stauffer, p. 171.

1944 *Nucleospira concinna*; Shimer & Shrock, p. 331, pl. 127, figs. 5-7.

1958 *Nucleospira concinna*; Stumm & Wright, p. 107.

Types. The original specimen figured by Hall (1843) was from shales of the Middle Devonian Hamilton Group, Moscow, New York, but a holotype was not assigned. Original types cannot be traced from previous references.

Description. Shell small to medium, biconvex, subcircular; hinge line short, occupying half of shell width; cardinal extremities rounded; surface of shell covered by concentrated lamellose growth lines.

Ventral valve moderately to strongly convex; ventral sulcus shallow in most specimens; anterior commissure weakly uniplicate; in minority of specimens, ventral valve and dorsal valve shallowly sulcate, producing slight emargination of anterior outline; ventral cardinal area apsacline, low, obscured by the incurvature of the beak.

Ventral interior with prominent teeth; dental plates absent but dental ridges present; diductor scars flabellate.

Dorsal valve moderately to strongly convex.

Dorsal interior with prominent cardinal flanges, extending ventro-posteriorly; crura pronounced; median ridge low; anteriorly, spires present but not well preserved in the sectioned specimens (Figure 2-33).

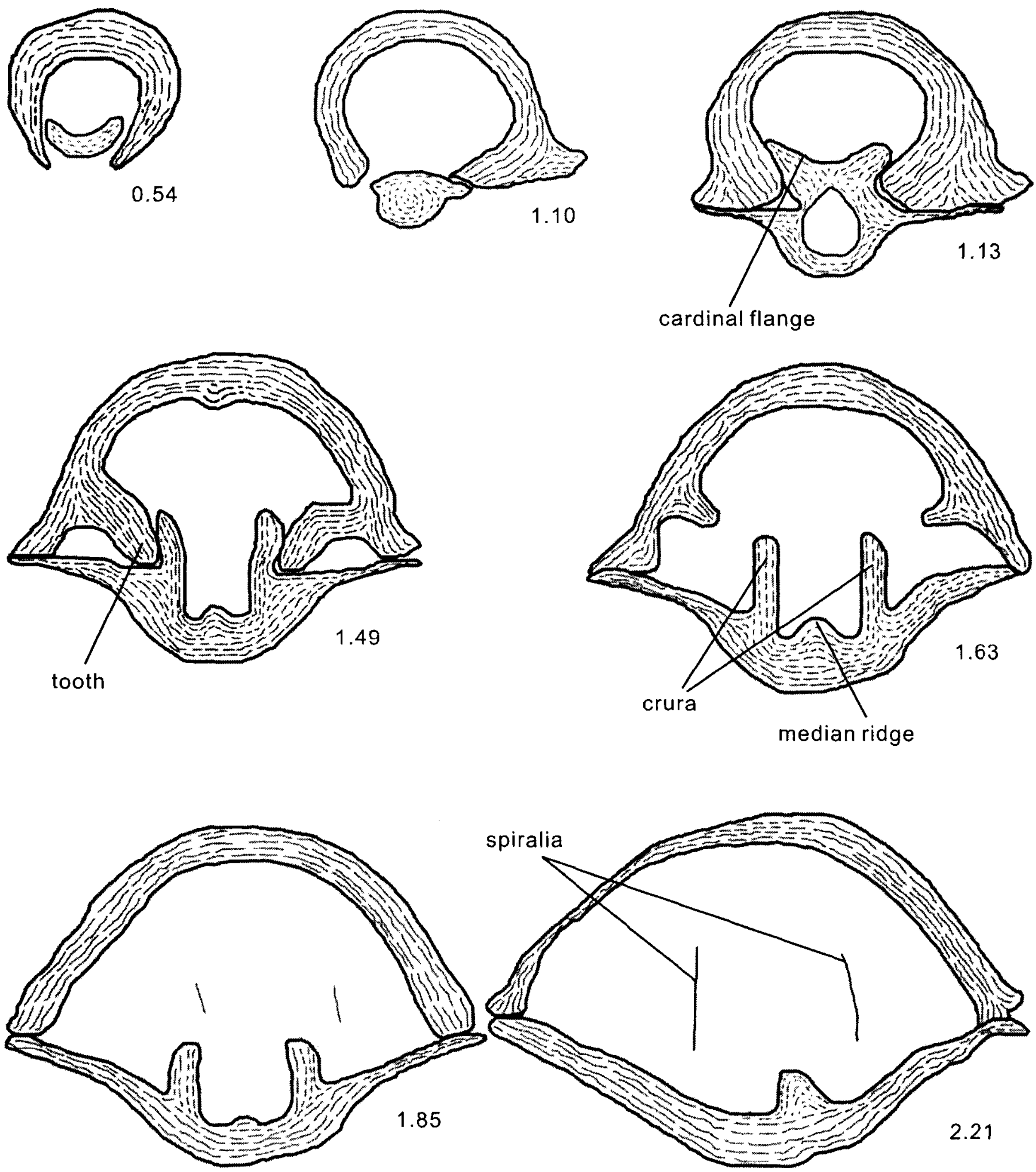


Fig. 2-33. Selected transverse serial sections of *Nucleospira concinna* (Hall, 1843). W 2892. Coral Unit, Hungry Hollow Member, Widder Formation. Collecting locality 5. Distances in mm from posteriortip of ventral umbo. X10.0

	W	L	T	L/W	T/W
MEAN	9.96	9.23	4.76	0.93	0.48
STD	1.74	1.66	1.07	0.05	0.07
MIN	6.21	6.08	2.38	0.84	0.33
MAX	14.12	13.22	8.20	1.11	0.61
N	75	75	75	75	75

Table 2-21. Statistical data of shell dimensions (mm) for complete specimens of *Nucleospira concinna* (Hall, 1843), sample from Collecting locality 5, Hungry Hollow Member, Widder Formation.

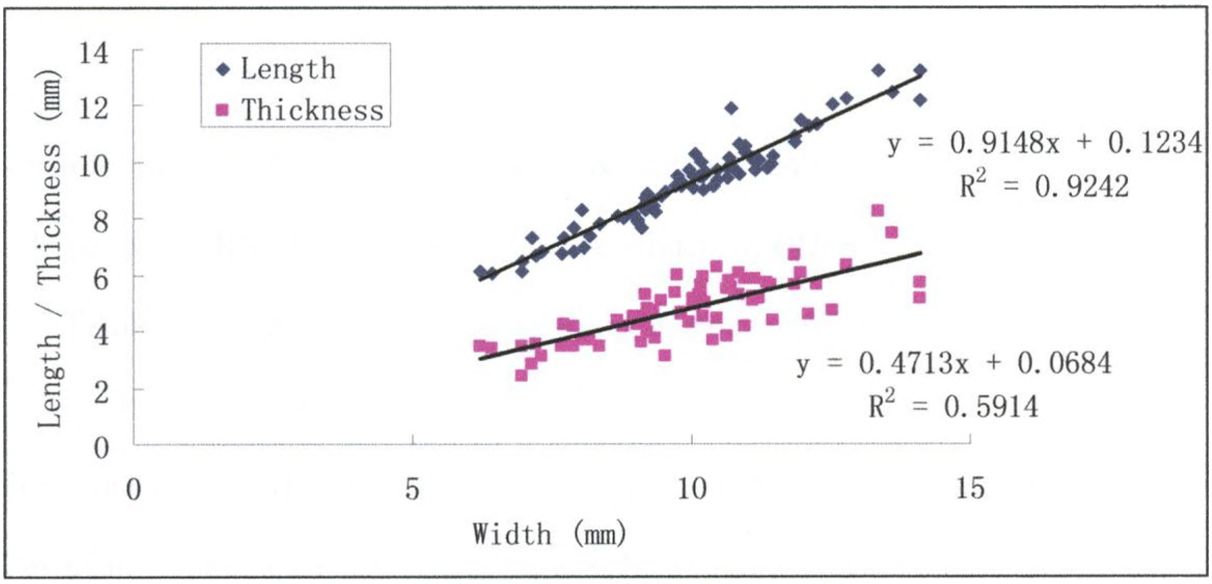


Fig. 2-34. Length-width and thickness-width graphs for complete specimens of *Nucleospira concinna* (Hall, 1843), sample from Collecting locality 5, Hungry Hollow Member, Widder Formation.

Material. Total 289 complete specimens and 56 incomplete specimens.

Occurrence. Hungry Hollow Member, Widder Formation; Arkona-Thedford-Ipperwash area, southwestern Ontario.

Discussion. *Nucleospira* cf. *inelegans* (Barrande, 1847) from the basal limestone of the Mandagery Park Formation (Lower Devonian) of New South Wales (Savage, 1971, p. 415-417, pl. 71, figs. 35-38) is easily distinguished from *N. concinna* (Hall, 1843) by its almost globular lateral profile with the greatest thickness posteriror to mid-length. *N. concinna* is more circular than *N. lens* (Schnur, 1851) (Li and Jones, 2003, p. 259, figs. 13.1-13.15, 15) and *N. stelcki* Li and Jones, 2003 (Li and Jones, 2003, p. 259, 261, figs. 13.16-13.27, 16), which are from the late Early Devonian to Middle Devonian Bird Fiord Formation, Arctic Canada. Furthermore, the width/thickness ratio (2.09) of *N. concinna* (Table 2-21) is greater than that (1.79) of *N. lens* and smaller than that (2.26) of *N. stelcki*.

Suborder RETZIIDINA Boucot, Johnson, & Staton, 1964b

Superfamily RHYNCHOSPIRINOIDEA Schuchert, 1929

Family PARAZYGIDAE Alvarez, Rong, & Boucot, 1998

Genus *Parazyga* Hall &Clarke, 1894b

Type species: *Atrypa hirsuta* Hall, 1857, shale beds, Hamilton Group (Middle Devonian), Darien Center, Genesee County, New York.

Parazyga cf. *hirsuta* (Hall, 1857)

Pl. 2-16, figs. 1-15; Table 2-22; Fig. 2-35; Fig. 2-36

Types. Hall's (1857) original description of *Parazyga hirsuta* included neither a holotype designation nor illustrations of specimens studied, but did indicate that the original specimens were collected from shale beds of the Middle Devonian Hamilton Group in Moscow, Livingston County and Darien, Genesee County. Original types cannot be traced from previous references.

Description. Shell medium, biconvex, transversely oval; shell covered with numerous, weak and rounded plications (at the mid-length of shell, 4-5 in number per 2 mm), crossed by sparse growth lines; anterior commissure uniplicate to rectimarginate.

Ventral valve moderately convex; sulcus ill-defined to shallow, commencing at the mid-length and widening anteriorly; foramen in permesothyridid position.

Ventral interior with prominent, concave dental plates; pedicle collar not preserved at the posterior portion of ventral valve in sectioned specimens.

Dorsal valve moderately convex; fold inconspicuous to low, commencing at the umbonal range and widening anteriorly.

Dorsal interior with well-developed outer hinge plates, projecting posteriorly as thin cardinal flanges; outer hinge plates with two widely separated vertical supports, enclosing marginal dental sockets; crural bases divergent (Figure 2-35).

Material. Total 25 complete specimens and 13 incomplete specimens.

Occurrence. Coral Unit, Hungry Hollow Member, Widder Formation; Arkona-Thedford-Ipperwash area, southwestern Ontario.

Discussion. In terms of exterior characters, *Parazyga* cf. *hirsuta* (Hall, 1857) is similar in shape to *P. hirsuta* (Hall, 1857); however, the former species differs in its lower

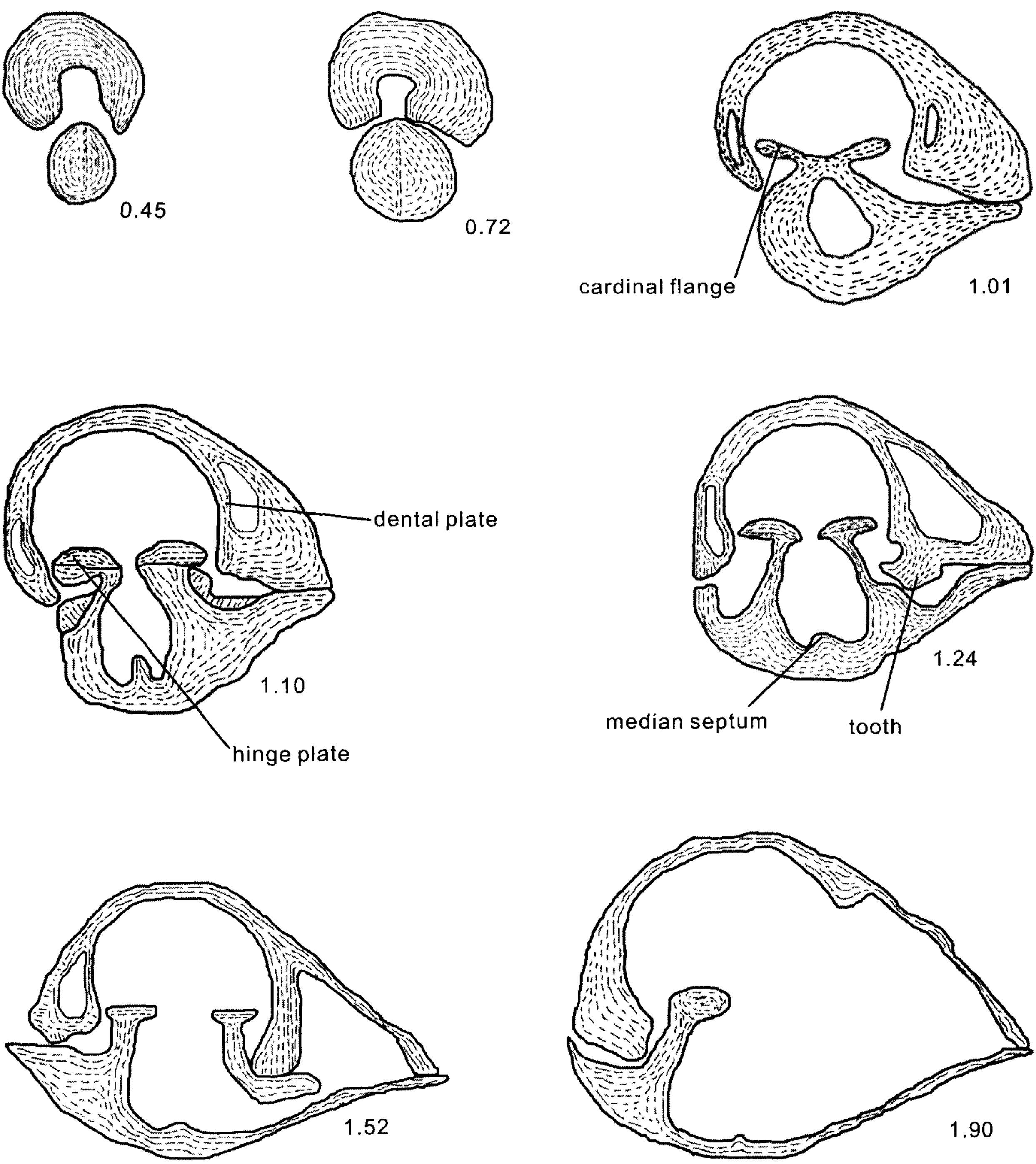


Fig. 2-35. Selected transverse serial sections of *Parazyga* cf. *hirsuta* (Hall, 1857). W 2896. Coral Unit, Hungry Hollow Member, Widder Formation. Collecting locality 3. Distances in mm from posterior tip of ventral umbo. X8.0

	W	L	T	L/W	T/W
MEAN	12.39	11.26	5.38	0.92	0.45
STD	2.78	2.27	1.23	0.06	0.10
MIN	6.41	6.49	3.11	0.82	0.29
MAX	15.44	14.55	7.54	1.01	0.60
N	15	15	15	15	15

Table 2-22. Statistical data of shell dimensions (mm) for complete specimens of *Parazyga* cf. *hirsuta* (Hall, 1857), sample from Collecting locality 1, Coral Unit, Hungry Hollow Member, Widder Formation.

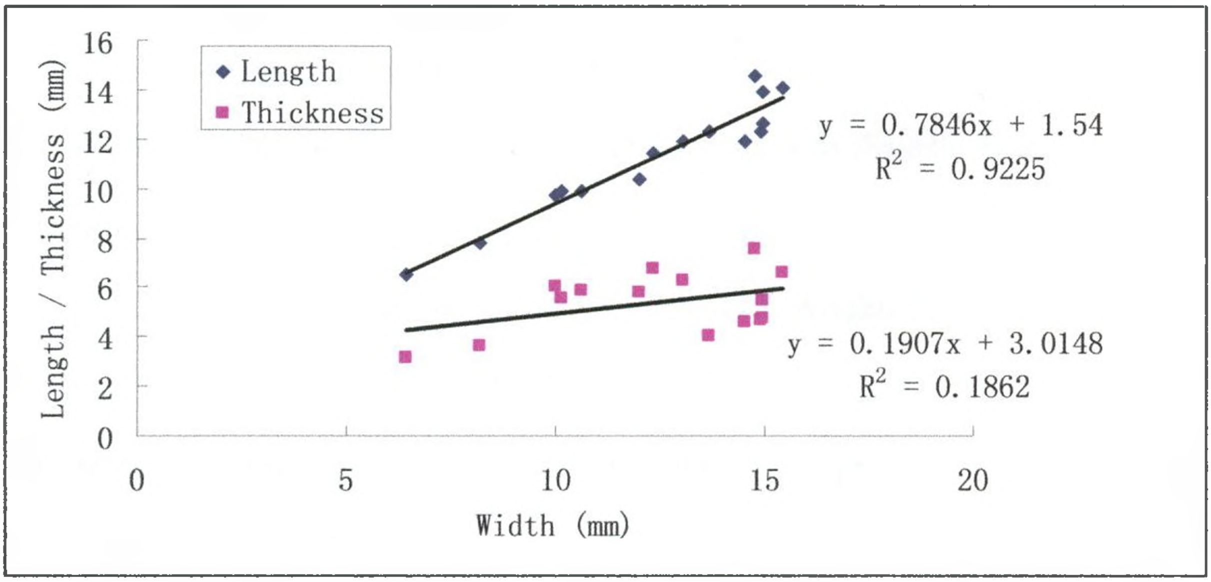


Fig. 2-36. Length-width and thickness-width graphs for complete specimens of *Parazyga* cf. *hirsuta* (Hall, 1857), sample from Collecting locality 1, Coral Unit, Hungry Hollow Member, Widder Formation.

degree of convexity, much shallower ventral sulcus, and much lower dorsal fold. In fact, in some specimens of *P.* cf. *hirsuta*, the ventral sulcus and dorsal fold are ill-defined.

Remarks. Some individuals were compressed and partially flattened and thus their values of thickness are less than those of their original thickness. Shimer and Grabau (1902, p. 153) mentioned the same name in their list of brachiopod species found in the Coral Unit of the Hamilton Group in Thedford, Ontario; however, since there is no relevant photo plate in their article, it's not certain that the species mentioned by Shimer and Grabau is the same as that described here.

Order SPIRIFERIDA Waagen, 1883

Suborder SPIRIFERIDINA Waagen, 1883

Superfamily CYRTOSPIRIFEROIDEA Termier & Termier, 1949

Family SPINOCYRTIIDAE Ivanova, 1959

Genus *Spinocyrtia* Frederiks, 1916

Type species: *Delthyris granulosa* Conrad, 1839, shale beds (Middle Silurian), locality uncertain.

Spinocyrtia ravenswoodensis Ehlers & Wright, 1955

Pl. 2-17, fig. 1-5

1955 *Spinocyrtia ravenswoodensis* Ehlers & Wright, p. 17, pl. 9, figs. 1-9; pl. 10, figs. 1-8; pl. 11, figs. 1-2.

1958 *Spinocyrtia ravenswoodensis*; Stumm & Wright, p. 121.

1963 *Spinocyrtia ravenswoodensis*; Wright & Wright, p. 121.

1964 *Spinocyrtia ravenswoodensis*; Peterson, p. 843.

2007 *Spinocyrtia ravenswoodensis*; Bartholomew & Brett, p. 111.

Types. Holotype UMMP 32682, upper part of the Widder Formation, Middle Devonian Hamilton Group, field near Ravenswood, about 0.4 mile (~ 0.64 km) northeast of the Ipperwash Beach Road and about 0.9 mile (~ 1.45 km) northwest of Highway 21, southwestern Ontario, Canada.

Description. Shell large, biconvex, transversely extended; surface of shell covered by simple rounded costae (mainly 17-19 in number per flank), crossed by irregular fine growth lines; hinge line straight, maximum width along hinge line; cardinal extremities acute, slightly extended; anterior commissure uniplicate; tear-shaped granules present on exterior surface.

Ventral valve moderately convex; umbonal region strongly convex, elevated above hinge line; ventral interarea high (7.2-8.0 mm), concave, apsacline; horizontal fine growth lines present in ventral interarea; delthyrium prominent, open; ventral sulcus subangular, deep, commencing at ventral beak, widening anteriorly; a narrow, deep median groove present in sulcus; beak prominent, incurved.

Ventral interior unknown.

Dorsal valve strongly convex; umbonal region strongly convex, elevated above hinge line; dorsal interarea linear; dorsal fold relatively low, with a deep median groove, originating at umbonal region and extending to anterior margin; dorsal beak inconspicuous.

Dorsal interior unknown.

Material. Total 9 incomplete specimens.

Occurrence. Widder Formation; Ipperwash Limestone; Arkona-Thedford-Ipperwash area, southwestern Ontario.

Discussion. Although *Spinocyrtia mongolica* Oleneva, 1998 from the Middle and Upper Devonian rocks of Mongolian Altai (Oleneva, 1998, p. 151, pl. 3, fig. 12a-e) is similar in outline to *S. ravenswoodensis* Ehlers & Wright, 1955, it differs in its smaller size (1.5 times smaller than *S. ravenwoodensis*) and absence of a longitudinal groove in the sulcus (Oleneva, 1998, p. 151).

Spinocyrtia granulosa (Conrad, 1839)

Pl. 2-17, figs. 6-10

1839 *Delthyris granulose* Conrad, p. 65.

1843 *Delthyris granulifera* Hall, p. 206-207, No. 85, figs. 1, 1a; ?figs. 1b-1d; No. 47, figs. 1, 1a; ? figs. 1b-1d.

1843 *Delthyris congesta* Hall, p. 206-207, No. 85, fig. 2, 2a; No. 47, figs. 2, 2a.

1857 *Spirifer granulifera* Hall, p. 163-164.

1857 *Spirifer arata* Hall, p. 161.

1867 *Spirifera granulifera* Hall, pl. 36, figs. 1-3, 5-10; ? figs. 11-13.

1867 *Spirifer congesta* Hall, p. 225.

1867 *Spirifera arata* Hall, p. 235.

1867 *Spirifer clintoni* Hall, p. 225.

1867 *Spirifera granulifera* var. *clintoni* Hall, pl. 37, figs. 1-4.

1894a *Spirifer granulosus*; Hall, pl. 28, fig. 11; ?figs. 12-13.

1894b *Spirifer granulosus*; Hall & Clarke, pl. 23, fig. 1; ? figs. 2-15.

1897 *Spirifer granulosus*; Schuchert, p. 391.

1899 *Spirifer granulosus*; Grabau, p. 210-211, fig. 118.

1899 *Spirifer granulosus*, var. *clintoni* Hall; Grabau, p. 211, fig. 118A.

1909 *Spirifer granulosus*; Grabau & Shimer, p. 328, fig. 417.

1915 *Spirifer granulosus*; Stauffer, p. 171.

1916 *Spinocyrtia granulosa*; Fredericks, p. 18.

1944 *Spinocyrtia granulosa*; Shimer & Shrock, p. 323, pl. 123, figs. 6-8.

1955 *Spinocyrtia granulosa*; Ehlers & Wright, p. 6, pl. 1,figs. 4-9; pl. 2, figs. 1-2; pl. 3.

1978 *Spinocyrtia granulosa*; Pitrat & Rogers, p. 1317.

2007 *Spinocyrtia granulosa*; Bartholomew & Brett, p. 111.

Types. Conrad's (1839) original description did not include a holotype designation, illustrations of specimens used, or the collection locality for the specimens, but indicated that the specimens were from shale beds of unit 7 (the lithologies of unit 7 in ascending order in Conrad (1839): Second Pentamerus Limestone, Helderberg Limestone, Helderberg Sandstone, and Gray Brachiopod Sandstone). Ehlers & Wright (1955) later determined that there were no shale beds in Conrad's (1839) so-called unit 7; but that "dark coloured shales" containing typical Hamilton fossils did occur in the overlying strata of Conrad's unit 8. Based on the fact that the brachiopod genus *Spinocyrtia* occurs in dark shale of the Hamilton Group of New York state, Ehlers & Wright (1955) deduced that the original specimens, *Delthyris granulose* identified by Conrad (1839), probably were from the shale beds of Unit 8 (Unit 8 of Conrad (1839) consists of a lower subunit of "black slate" overlain by an upper unit of "dark coloured shale"). Ehlers & Wright (1955) commented that Conrad's (1839) original specimens were lost with little likelihood that they would be ultimately found. The neotype (E 9572) is housed in the Buffalo Museum of Science.

Description. Shell large, biconvex, transversely extended; surface of shell covered by simple rounded costae (21-23 in number per flank); costae high and rounded at the umbonal region, becoming lower and thicker anteriorly, crossed by numerous irregular fine growth lines; tear-shaped granules present on the microfila; hinge line straight, the maximum width along hinge line; cardinal extremities acute, slightly extended; anterior commissure uniplicate.

Ventral valve moderately convex; umbonal region moderately convex, elevated above hinge line; ventral interarea high (8.8-9.0 mm), concave, apsacline; horizontal fine growth lines present in ventral interarea; delthyrium prominent, open; ventral sulcus subangular, deep, commencing at ventral beak and widening anteriorly; median groove narrow, shallow, present in sulcus; granules in sulcus with linear arrangement; beak prominent, incurved.

Ventral interior unknown.

Dorsal valve more convex than ventral valve; umbonal region moderately convex; dorsal interarea linear; dorsal fold relatively high, with a shallow median groove, originating at the umbonal region and extending to anterior margin; dorsal beak inconspicuous.

Dorsal interior unknown.

Material. Total 13 incomplete specimens.

Occurrence. Widder Formation; Ipperwash Limestone; Arkona-Thedford-Ipperwash

area, southwestern Ontario.

Discussion. Spinocyrtia ravenswoodensis Ehlers& Wright, 1955 is distinguished from *S. granulosa* (Conrad, 1839) by its larger size, more convex umbonal region, more incurved ventral beak, deeper median groove in sulcus, and lower dorsal fold with a deeper median groove. *S. milwaukeensis* (Cleland, 1911) from the Milwaukee Formation (Middle Devonian) of southeastern Wisconsin (Griesemer, 1965, p. 283, pl. 5, figs. 10-12) resembles *S. granulosa* in overall shape. However, the former species differs from the latter in its deeper sulcus, lower fold, less concaved ventral interarea, less incurved beak, and lack of tear-shaped granules on the shell surface. *S. granulosa* is also similar to *S. clintoni* (Hall, 1857) from the Norway Point Formation of the Middle Devonian Traverse Group of Michigan (Pitrat and Rogers, 1978, p. 1319-1323, text-figs. 1-8), but is distinguished from the latter by its larger size, less developed median groove on the fold, and a more rounded bottom on the sulcus. *S. mongolica* Oleneva, 1998 from the Middle and Upper Devonian rocks of Mongolian Altai (Oleneva, 1998, p. 151, pl. 3, fig. 12a-e) differs from *S. granulosa* in having a less than half size (L = 25 mm), lower ventral interarea(up to 5 mm), a straight beak, and less numerous costae (15-18 in number on each flank).

Spinocyrtia mourantae Ehlers& Wright, 1955

Pl. 2-18, figs. 1-5

1955 *Spinocyrtia mourantae* Ehlers & Wright, p. 10, pl. 1, figs. 1-3; pl. 4, figs. 1-4; pl.

5, figs. 1-2.

1958 *Spinocyrtia mourantae*; Stumm & Wright, p. 93.

1978 *Spinocyrtia mourantae*; Pitrat & Rogers, p. 1317.

Types. Holotype UMMP 31530, Arkona Shale Formation, about 28 feet (~ 8.53 m) below the base of the Hungry Hollow Member, Middle Devonian Hamilton Group, Bank of Ausable River at No. 4 Hill, Bosanquet Township, Lambton County, Ontario.

Description. Shell large, biconvex, transversely extended; surface of shell covered by simple rounded costae (mainly 16-18 in number per flank) and numerous fine radiating microfila, crossed by irregular fine growth lines; minute tear-shaped granules present on microfila; hinge line straight, the maximum width along hinge line; cardinal extremities rounded; anterior commissure uniplicate.

Ventral valve moderately convex; umbonal region moderately convex, elevated above hinge line; ventral interarea high (~ 9.6 mm), flat to slightly concave, apsacline; horizontal fine growth lines present in ventral interarea; delthyrium prominent, large, open; ventral sulcus subangular, shallow, broad, commencing at ventral beak, widening anteriorly; a broad, flat median groove present in sulcus; beak inconspicuous.

Ventral interior unknown.

Dorsal valve more convex than ventral valve; umbonal region moderately convex; dorsal interarea linear; dorsal fold broad, low, with a shallow and wide but poorly defined median groove, originating at the umbonal region and extending to anterior margin; dorsal beak inconspicuous.

Dorsal interior unknown.

Material. Total 3 complete specimens and 5 incomplete specimens.

Occurrence. Arkona Shale Formation; Arkona-Thedford-Ipperwash area, southwestern Ontario.

Discussion. *Spinocyrtia mourantae* Ehlers& Wright, 1955 differs from *S. ravenswoodensis* and *S. granulosa* in its relatively flat and higher ventral interarea, shallower ventral sulcus with a broader and flat median groove, and lower dorsal fold with a wider and shallower median groove. *S. mongolica* Oleneva, 1998 from the Middle and Upper Devonian rocks of Mongonian Altai (Oleneva, 1998, p. 151, pl. 3, fig. 12a-e) is distinguished from *S. mourantae* in having transversly-elongated shape and an indistinct, narrower fold (Oleneva, 1998, p. 151).

Spinocyrtia parvigranulata Ehlers & Wright, 1955

Pl. 2-18, figs. 6-10

1955 *Spinocyrtia parvigranulata* Ehlers & Wright, p. 12, pl. 4, figs. 5-11; pl. 5, figs. 3.

1958 *Spinocyrtia parvigranulata*; Stumm & Wright, p. 116

1961 *Spinocyrtia parvigranulata*; Wright & Wright, p. 296.

Types. Holotype UMMP 32457, the top part of the Widder Formation, Hamilton Group (Middle Devonian), bed of Golden Creek, about 1.25 mile (~ 2.01 km) west and 0.75 mile (~ 1.21 km) north of Thedford, Bosanquet Township, Lambton County, Ontario.

Description. Shell large, biconvex, transversely extended; surface of shell covered by simple rounded costae (mainly 17-20 in number per flank) and numerous fine radiating microfila, crossed by irregular fine growth lines; minute tear-shaped granules present on microfila; maximum width along hinge line; hinge line straight; cardinal extremities extended; anterior commissure uniplicate.

Ventral valve moderately convex; umbonal region moderately convex, elevated above hinge line; ventral interarea moderately high (~ 7.00 mm), slightly concave, apsacline; horizontal fine growth lines present in ventral interarea; ventral sulcus subangular, shallow, broad, concave at the anterior region, commencing at ventral beak and widening anteriorly; median groove broad, shallow, present in sulcus; beak small, incurved.

Ventral interior unknown.

Dorsal valve more convex than ventral valve; umbonal region moderately convex, slightly elevated above hinge line; dorsal interarea linear; fold broad, high, with a shallow and narrow median groove, beginning from umbonal region, disappearing anteriorly; dorsal beak inconspicuous.

Dorsal interior unknown.

Material. Total 11 incomplete specimens.

Occurrence. Widder Formation; Arkona-Thedford-Ipperwash area, southwestern Ontario.

Discussion. Spinocyrtia parvigranulata Ehlers & Wright, 1955 is distinguished from the congeneric species by its shallow, broad and concave sulcus, broad and higher fold, and smaller-sized granules on shell surface.

Genus *Mediospirifer* Bublichenko, 1956

Type species: *Delthyris medialis* Hall, 1843, New York (the exact horizon and locality unknown), Givetian (Middle Devonian).

? *Mediospirifer* sp.

Pl. 2-9, figs. 11-15

Description. Shell large, ventribiconvex, strongly transversely extended with acute cardinal extremities; surface of shell marked with numerous, rounded, simple plications (18-20 in number per flank), covered by closely spaced, thin and slightly lamellose growth lines; maximum width along with hinge line; hinge line straight; anterior commissure uniplicate.

Ventral valve moderately convex; ventral sulcus prominent, relatively deep, narrow, commencing at ventral beak, widening anteriorly; ventral interarea moderately high (~ 6.0 mm), slightly curved, procline; horizontal fine growth lines present in ventral interarea; beak small, incurved; delthyrium prominent; stegidial plates present.

Ventral interior unknown.

Dorsal valve slightly convex; dorsal fold prominent but low, beginning at ventral beak, widening anteriorly; umbonal region elevated above the hinge line; dorsal interarea relatively low, linear; dorsal beak small, incurved.

Dorsal interior unknown.

Material. Total 1 complete specimen.

Occurrence. Coral Unit, Hungry Hollow Member, Widder Formation; Arkona-Thedford-Ipperwash area, southwestern Ontario.

Discussion. The exterior characters of this specimen closely resemble those in genus *Mediospirifer*, except that the ventral interarea in this specimen is procline whereas the ventral interarea in genus *Mediospirifer* is steeply apsacline (Johnson, 2006, p. 1724).

Since the specimen is borrowed from the Museum of Paleontology, the University of Michigan, and is not allowed to be sectioned, the interior characters are unknown. This specimen is therefore temporarily assigned to genus *Mediospirifer*. The identification at species level requires more samples and further study.

Discussion. This specimen differs from the four hypotype specimens of *M. audaculus* (Conrad) (UMMP 61042A-D, from Unit 7 or 9 of the Middle Devonian Silica Formation, Quarry of the Medusa Portland Cement Co., Sylvania, Lucas County, Ohio, U.S.A.) in its much more transverse shape and procline ventral interarea.

Remarks. This species is rare in Arkona-Thedford-Ipperwash area.

Superfamily AMBOCOELIOIDEA George, 1931

Family AMBOCOELIIDAE George, 1931

Subfamily AMBOCOELIINAE George, 1931

Genus *Ambocoelia* Hall, 1860a

Type Species: *Orthis umbonata* Conrad, 1842, shale beds (exact horizon and locality unknown, Upper Silurian), Moscow, Livingston County, New York.

Ambocoelia tuberculata Goldman & Mitchell, 1990

Pl. 2-14, figs. 16-20; Table 2-23; Fig. 2-37

1902 *Ambocoelia umbonata*; Shimer & Grabau, p. 158.

1967 *Ambocoelia* sp.; Mitchell, p. 178.

1990 *Ambocoelia tuberculata* Goldman & Mitchell, p. 83, 85, figs. 5.6-5.10, 11, 12.3, 12.4.

Types. Holotype BMS E26490, Hungry Hollow Member, Widder Formation, Middle Devonian Hamilton Group, Ausable River at Hungry Hollow, Arkona, West Williams Township, Middlesex County, Ontario.

Description. Shell small, planoconvex; hinge line megathyrid; surface of shell covered obscure radial striae, crossed by very faint concentric growth lines; cardinal angle near 90 degrees; commissure slightly uniplicate to rectimarginate.

Ventral valve strongly convex; sulcus shallow and well-defined, commencing at beak; beak small and incurved; interarea low (2.0 ~ 2.7 mm), apsacline.

Ventral interior with prominent teeth; teeth nearly rectangular; dental plates absent.

Dorsal fold ill-defined; dorsal interarea linear.

Dorsal interior with bilobed, tuberculate cardinal process; crural plates small; outer hinge plates preserved; spiralia present (Figure 2-37).

Material. Total 11 complete specimens and 17 incomplete specimens.

Occurrence. Arkona Shale Formation; Widder Formation; Arkona-Thedford-Ipperwash area, southwestern Ontario.

Discussion. Although *Ambocoelia tuberculata* Goldman & Mitchell, 1990 has higher ratios of width of hinge line to width of shell (W_l/W) (Table 2-23, Table 2-24), its external features closely resemble those of *A. umbonata* (Conrad, 1842) from the Middle Devonian rocks of New York State. However, *A. tuberculata* can be distinguished by the different shape of its cardinal process and its more developed crural plates (Goldman and Mitchell, 1990). *A. praecox dorsiplicata* Savage, 1969 from the early Siegenian (Lower Devonian) Mandagery Park Formation of New South

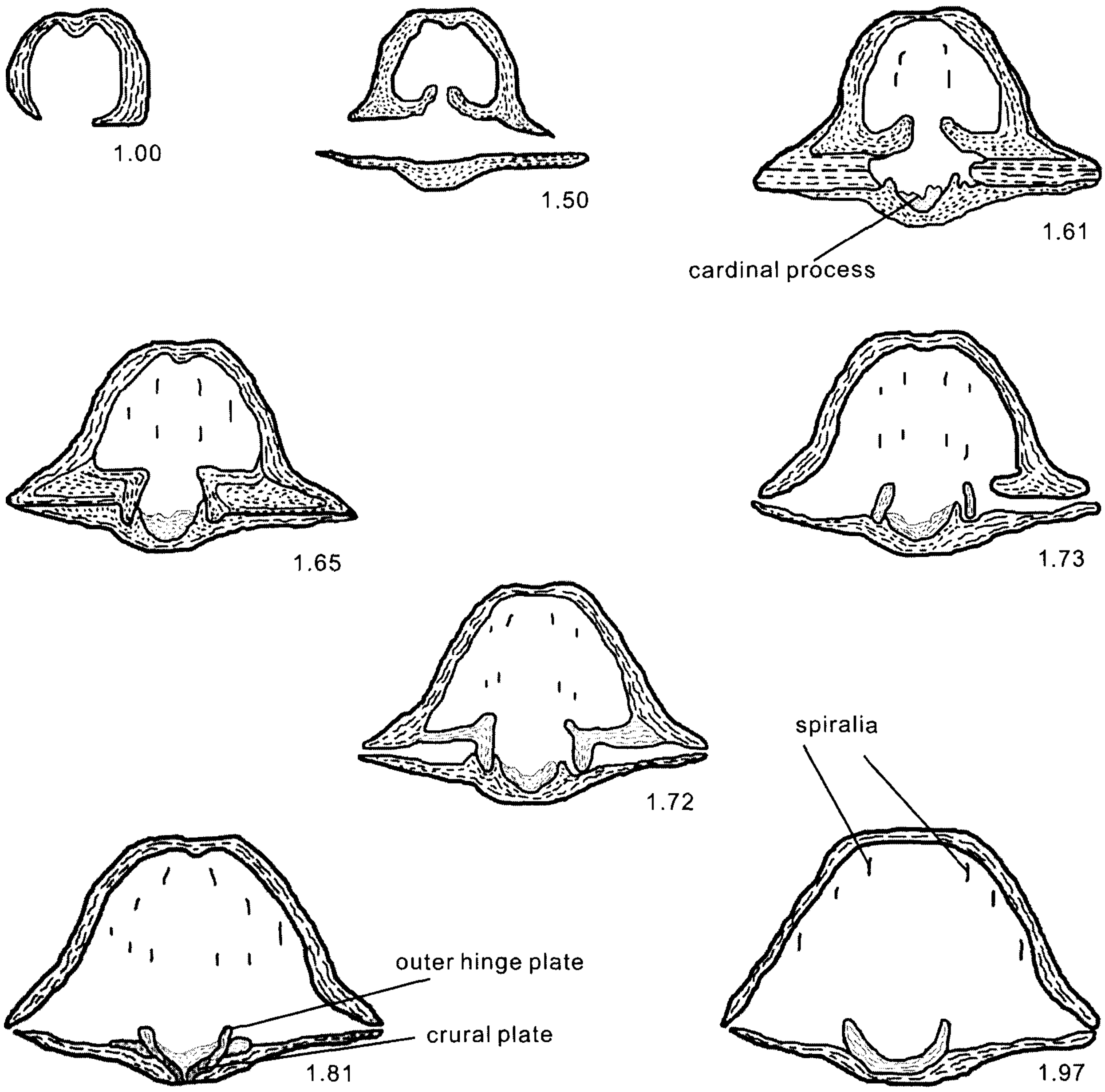


Fig. 2-37. Selected transverse serial sections of *Ambocoelia tuberculata* Goldman & Mitchell, 1990. W 2857. Coral Unit, Hungry Hollow Member, Widder Formation. Collecting locality 5. Distances in mm from posterior tip of ventral umbo. X8.0

	W	L	T	W_1	H_1	L/W	T/W	W_1/W
MEAN	7.72	7.60	4.88	7.00	1.82	0.98	0.63	0.91
STD	1.04	1.37	0.71	0.89	0.31	0.09	0.07	0.04
MIN	6.64	5.39	4.18	6.17	1.40	0.81	0.53	0.83
MAX	9.24	9.87	6.30	8.45	2.31	1.11	0.71	0.96
N	8	8	8	6	6	8	8	6

Table 2-23. Statistical data of shell dimensions (mm) for complete specimens of *Ambocoelia tuberculata* Goldman & Mitchell, 1990, sample from Collecting locality 3, Thedford Member, Widder Formation.

	W	L	T	W_1	H_1	L/W	T/W	W_1/W
MEAN	6.97	6.48	4.55	6.13	2.22	0.93	0.65	0.88
STD	1.33	1.32	0.96	1.15	0.54	0.09	0.05	0.03
MIN	4.53	4.58	3.20	3.98	1.59	0.79	0.56	0.80
MAX	8.90	8.97	6.08	7.77	3.29	1.10	0.74	0.91
N	16	16	16	16	16	16	16	16

Table 2-24. Statistical data of shell dimensions (mm) for complete specimens of *Ambocoelia umbonata* (Conrad, 1842), sample from an outcrop, 2 miles northeastern of Darien, Genesee County, New York, Centerfield Member, Ludlowville Formation, Hamilton Group.

Wales, Australia (Savage, 1969, p. 478-480, pl. 90, figs. 1-21) is distinguished from *A. tuberculata* by its shallower ventral sulcus, weak dorsal fold, less concave ventral interarea, and much longer and widely divergent sockets. *A. ectypa* Baranov & Alkhovik, 2006 from the Middle Zagadochninskaya Subformation (Givetian stage) of southern Verkhoyansk Region, Northeastern Russia (Baranov and Alkhovik, 2006, p. 163-166, pl. 7, figs. 1-4) differs from *A. tuberculata* in its smaller size, less curved ventral interarea, and its distinctive surface ornamentation (sharp projections and thin spines arranged in concentric rows on the surface of the projections).

Suborder DELTHYRIDINA Ivanova, 1972

Superfamily DELTHYRIDOIDEA Phillips, 1841

Family MUCROSPIRIFERIDAE Boucot, 1959a

Subfamily MUCROSPIRIFERINAE Boucot, 1959a

Genus *Mucrospirifer* Grabau, 1931

Type species: *Delthyris mucronatus* Conrad, 1841, shale beds, Hamilton Group (Middle Devonian), Darien Center, Genesee County, New York.

Mucrospirifer mucronatus (Conrad, 1841)

Pl. 2-19, figs. 1-20; Pl. 2-20, figs. 1-15; Pl. 2-21, figs. 1-20; Pl. 2-22, figs. 1-20; Pl. 2-23, figs. 1-10; Fig. 2-38 to Fig. 2-54

1841 *Delthyris mucronatus* Conrad, p. 54.

1842 *Delthyris mucronata*; Vanuxem, p. 150, fig. 3.

1857 *Spirifer mucronata*; Billings, p. 474, pl. 7, figs. 9, 10.

1858 *Spirifer mucronata*; Rogers, p. 828, fig. 668.

1862 *Delthyris mucronata*; Hall, pl. 11, fig. 18.

1867 *Spirifera mucronata*; Hall, p. 216, pl. 34, figs. 1-32.

1883 *Spirifera mucronata*; Hall, pl. 59, figs. 13-22.

1889 *Spirifera mucronata*; Nettelroth, p. 126, pl. 31, figs. 10-11.

1890 *Spirifer mucronatus* variety; Williams, pl. 12, fig. 13.

1894b *Spirifer mucronatus*; Hall and Clarke, p. 14, 17, 36, pl. 29, fig. 8; pl. 34, figs. 13-22.

1902 *Spirifer mucronatus* var. *arkonensis* Shimer & Grabau, p. 170-171.

1902 *Spirifer mucronatus* var. *thedfordensis* Shimer & Grabau, p. 171-176.

1910 *Spirifer mucronatus* var. *attenuatus* Grabau; Grabau & Reed, p. 1-2.

1910 *Spirifer profundus* Grabau; Grabau & Reed, p. 1-2.

1910 *Spirifer profundus* mut. *intermedia* Grabau; Grabau & Reed, p. 2.

1910 *Spirifer mucronatus* mut. *lata* Grabau; Grabau & Reed, p. 2.

1912 *Spirifer mucronatus* var. *attenuatus* Grabau; Grabau & Reed, p. 767-768.

1912 *Spirifer mucronatus* var. *multiplicatus* Grabau; Grabau & Reed, p. 767-768.

1912 *Spirifer profundus* Grabau; Grabau & Reed, p. 767-768.

1912 *Spirifer profundus* mut. *intermedia* Grabau; Grabau & Reed, p. 768.

1912 *Spirifer mucronatus* mut. *lata* Grabau & Reed, p. 768.

1915 *Spirifer mucronatus*; Stauffer, p. 167.

1915 *Spirifer mucronatus arkonense* Stauffer, p. 167.

1915 *Spirifer mucronatus thedfordense* Stauffer, p. 167.

1915 *Spirifer mucronatus* mut. *alpenensis* Grabau; Mook, p. 176-177.

1915 *Spirifer mucronatus* mut. *multiplicatus* Grabau; Mook, p. 177-179.

1915 *Spirifer mucronatus* mut. thedfordensis; Mook, p. 182-184.

1915 *Spirifer mucronatus* mut. *attenuatus* Grabau; Mook, p. 184-186.

1915 *Spirifer mucronatus* mut. *profundus* Grabau, p. 179-182.

1916 *Spirifer mucronatus*; stauffer, p. 483.

1927*Spirifer mucronatus* var. *prolificum* Stewart, p. 47-49, pl. IV, figs. 9-14.

1931 *Mucrospirifer thedfordensis* Grabau, p. 408-409.

1943 *Spirifer mucronatus*; Caley, p. 54.

1944 *Mucrospirifer thedfordensis*; Shimer and Shrock, p. 321, pl. 122, figs. 15-16.

1956 *Mucrospirifer alpenensis* (Grabau); Stumm, p. 85, pl. I, figs. 13-18.

1956 *Mucrospirifer prolificus* (Stewart); Stumm, p. 85-86, pl. I, figs. 1-12.

1956 *Mucrospirifer multiplicatus* (Grabau); Stumm, p. 86-87, pl. II, figs. 1-11.

1956 *Mucrospirifer attenuatus* (Grabau); Stumm, p. 87, pl. II, figs. 12-15.

1956 *Mucrospirifer profundus* (Grabau); Stumm, p. 87-88, pl. III, figs. 1-7.

1956 *Mucrospirifer grabaui* Stumm, p. 88, pl. III, figs. 8-17.

1956 *Mucrospirifer latus* (Grabau); Stumm, p. 89, pl. III, figs. 21-27.

1956 *Mucrospirifer grabaui* Stumm, var.A, p. 89, pl. III, figs. 18-20.

1961 *Mucrospirifer thedfordensis* (Shimer and Grabau); Wright & Wright, p. 295.

1963 *Mucrospirifer cooperi* Wright & Wright, p. 127-128, Pl. 1, fig. 1; Pl. 2, figs. 16-27; Pl. 3, fig. 1.

1964 *Mucrospirifer arkonensis* (Shimer and Grabau); Tillman, p. 955.

1964 *Mucrospirifer norwoodensis* Tillman, p. 963, pl. 156, figs. 39-44.

Types. Conrad (1841) neither designated a holotype nor included illustrations of specimens in his original description of this species. He did, however, indicate that specimens upon which he based his description were from shales of the Upper Silurian (now recognized as Middle Devonian) Hamilton Group, at Darien Center, Genesee County, New York. A plastotype of *Mucrospirifer mucronatus* (Conrad, 1841) from the UMMP (UMMP 31536 from a quarry exposure of the Middle Devonian Skaneateles Formation (Hamilton Group) on the campus of Colgate University, Hamilton, Madison County, New York) was selected for use in the present study.

The following types were also used for comparative purposes in the present study:

1. Lectotype of *M. alpenensis* (Grabau) (UMMP 31648) from upper beds of the Middle Devonian Ferron Point Formation (Traverse Group), Shale Pit, Alpena Portland Cement Co., 6 miles (~ 9.65 km) north of Alpena, Michigan.
2. Lectotype of *M. multiplicatus* (Grabau) (UMMP 31633) from basal beds of the Middle Devonian Genshaw Formation, Traverse Group, ledges along Long Lake Road, south end of Long Lake, Alpena County, Michigan.
3. Lectotype of *M. attenuatus* (Grabau) (UMMP 31658) from the Middle Devonian Norway Point Formation (Traverse Group), Seven-Mile Dam on Thunder Bay River, 5 miles (~ 8.05 km) northwest of Alpena, Michigan.
4. Lectotype of *M. profundus* (Grabau) (UMMP 31659) from the Middle Devonian Norway Point Formation (Traverse Group), Seven-Mile Dam on Thunder Bay River, 5 miles (~ 8.05 km) northwest of Alpena, Michigan,.
5. Lectotype of *M. grabaui* Stumm (UMMP 33324) from the Middle Devonian Potter Farm Formation (Traverse Group), Stony Point, Thunder Bay, near Alpena, Michigan,.

6. Lectotype of *M. latus* (Grabau) (UMMP 31649) from the Middle Devonian Norway Point Formation (Traverse Group), Seven-Mile Dam on Thunder Bay River, 5 miles (~ 8.05 km) northwest of Alpena, Michigan.

7. Holotype of *M. cooperi* Wright & Wright (UMMP 46132) from the Middle Devonian Ipperwash Limestone (Hamilton Group), shore of Lake Huron, 2 miles (~ 3.22 km) south of Kettle Point, Lambton County, Ontario.

8. Holotype of *M. norwoodensis* Tillman (UMMP 44123) from upper part of the Middle Devonian Petoskey Formation (Traverse Group), small pit in limestone about 1.5 miles (~ 2.41 km) north of Norwood, Charlevoix County, Michigan.

Shimer & Grabau's (1902) original description of *M. thedfordensis* (Shimer & Grabau) was based on specimens from the Middle Devonian Hamilton Group of the Thedford area in Ontario, although the original description of this taxon included neither illustrations nor a designated holotype. Since the original specimens cannot be traced, some hypotypes from the UMMP (UMMP 44112, UMMP 44113, UMMP 44115, UMMP 44116, UMMP 44120), all previously figured by Tillman (1964) were selected for this study. UMMP 44112 is from the Middle Devonian Alpena Limestone, Traverse Group, collected at the Huron Portland Cement quarry located on eastern edge of Alpena, Alpena County, Michigan. UMMP 44113 and UMMP 44120 are from the Middle Devonian Widder Formation, Hamilton Group, collected on the east side of county road about 0.5 mile (~ 0.81 km) southeast of intersection of Highway 21 and Port Frank Road, Bosanquet Township, Lambton County, Ontario. UMMP 44115 is from the Middle Devonian Potter Farm Formation, Traverse Group, collected from excavations at the Alpena City waterworks and ledges outcropping on beach at Stony

Point, south edge of Alpena, Alpena County, Michigan. UMMP 44116 is from the Middle Devonian Petoskey Formation, Traverse Group, collected from the Kegomic quarry on south shore of Mud Lake, east of Harbor Springs Road (M. 131), about 0.25 mile (~ 0.40 km) north of its termination on U.S. 31, 1 mile (~ 1.61 km) east of Bay View, Emmet County, Michigan.

Shimer & Grabau's (1902) original description of *M. arkonensis* (Shimer & Grabau) was based on specimens from the Middle Devonian Hamilton Group in the Thedford area of Ontario, but did not include a holotype designation nor illustrate any specimen. Since the original specimens cannot be traced, a hypotype of *M. arkonensis* (Shimer & Grabau) from the UMMP (UMMP 44122 from Arkona Shale Formation, Hamilton Group, north bank of Ausable River at Hungry Hollow, about 2 miles (~ 3.22 km) east and 0.25 mile (~0.40 km) north of center of Arkona, Middlesex County, Ontario) was used in the present study. It should be noted that Tillman (1964) assigned this same specimen to *M. mucronatus*.

Description. Shell large, biconvex, transversely extended, maximum width along straight hingeline; cardinal extremities mucronate; flanks with simple, rounded to subangular plications; plication number varies from specimen to specimen (usually 8-23 in number per flank); plications crossed by numerous imbricate growth lamellae, growth lamellae more frequent and distinct in anterior area.

Ventral umbonal area moderately to strongly convex, forming apical angle (main range: 88°-125°), relatively high, with beak extending (main range: 0.59-1.95 mm) above hinge line in adult shells, ventral interarea low to relatively high (main range: 0.5-5.5 mm high), apsacline to orthocline, horizontal fine growth lines present within interarea; beak small, slightly to strongly incurved; stegidial plates present; sulcus beginning from apex, widening anteriorly; width and depth of ventral sulcus varies from specimen to specimen, sulcus narrow and deep with a median groove in some specimens (e.g., Pl. 2-21, figs. 2, 7, 12, 17), narrow and shallow with a median ridge in some specimens (e.g., Pl. 2-19, figs. 2, 7, 12, 17), wide and shallow with a slight median groove in some specimens (e.g., Pl. 2-22, fig. 7); delthyrium obvious in some specimens (e.g. Pl. 2-21, figs. 6, 16).

In some specimens, ventral interior with obvious median septum in the early stages; for all examined specimens, ventral interior with dental plates; dental plates showing extreme variation in length and width and degree of convergence (ranging from parallel to convergent); dental plates fused to valve wall in some cases (e.g., Figure 2-47, Figure 2-54); shape of teeth varies from square to round.

Dorsal umbonal area slightly to moderately convex; fold low (e.g. Pl. 2-20, figs. 5, 10, 15; Pl. 2-23, figs. 5) to relatively high (e.g. Pl. 2-23, fig. 10), with a median groove in some specimens (e.g. Pl. 2-23, figs. 1, 6) but not in other (e.g. Pl. 2-21, fig. 1, 6; Pl. 2-22, fig. 11); fold originating at apex and widening anteriorly; dorsal interarea linear.

Dorsal interior with comb-shaped cardinal process (tiny septa 8-16 in number); anteriorly, dental sockets present, becoming larger anteriorly; crural plates obvious; crura well-developed and long; brachidium present, containing about 8-14 whorls; median septum present in some specimens (for their internal structures, see Figure 2-42 to Figure 2-58).

Material. Total 1220 complete specimens and 850 incomplete specimens.

Occurrence. Arkona Shale Formation; Widder Formation; Ipperwash Limestone;

Arkona-Thedford-Ipperwash area, southwestern Ontario.

Discussion. Mucrospirifer is, by far, the most common brachiopod genus in the Middle Devonian Hamilton Group of southwestern Ontario, Appalachian and Michigan basins. Many previous authors assigned specimens of *Mucrospirifer* to different species purely on the basis of external shell characteristics such as: overall shell size, width/length and width/thickness ratios, presence or absence of mucronate points, number of costae, width of costae, length of interarea, fold and sulcus morphology, and the presence/absence of a median ridge in the sulcus and median groove on the fold. Reflecting its highly variable morphology, more than ten different species of *Mucrospirifer* have been proposed. Originally named *Delthyris* by Conrad (1841), the genus was later changed to *Spirifer*, *Spirifera,* and finally, *Mucrospirifer*.

Based on the morphology of the specimens from the Traverse Group, Stumm (1956) revised the descriptions and illustrations of Grabau's species and assigned them to six species: *M. alpenensis, M. multiplicatus, M. attenuatus, M. profundus, M. grabaui, M. latus.* He also described and illustrated *M. prolificus* Stewart from the Middle Devonian Traverse Group of Michigan and the Middle Devonian Silica Shale of Ohio. Based on characters of the fold and sulcus, he divided the six species into three lineages, the *M. alpenensis* lineage (*M. alpenensis* and *M. prolificus* are included), the *M. multiplicatus* lineage (*M. multiplicatus* and *M. attenuatus* are included), and the *M. profundus* lineage (*M. profundus, M. grabaui,* and *M. latus* are included). Stumm (1956) distinguished members of the *M. alpenensis* lineage as having a wide and shallow sulcus with a flat base and no median ridge, and a low and relatively flat fold which is generally without a median groove. The *M. alpenensis* lineage was recognized by that author to occur in the calcareous shales of the lower Traverse Group of Michigan, with *M. prolificus* also occurring in the Silica Shale of northwestern Ohio and southeastern Michigan. Stumm (1956) claimed members of the *M. multiplicatus* lineage possess a sulcus with a distinct median ridge and a fold bearing a distinct median groove. He noted this lineage occurred in Traverse Group strata of the Thunder Bay region, Alpena county, Michigan, with *M. multiplicatus* and *M. attenuatus* occurring in the Genshaw and Norway Point formations respectively. Stumm (1956) identified members of the *M. profundus* lineage as having of a low, convex fold and a deep, V-shaped sulcus. He noted *M. profundus* occurred in the Norway Point, Potter Farm, and lower Petoskey formations, *M. grabaui* occurred in the Four-Mile Dam, Potter Farm, Gravel Point, and lower Petoskey formations, and *M. latus* was confined to the Alpena Limestone, and Norway Point and Potter Farm formations.

Tillman (1964) studied the morphological variation of *Mucrospirifer* specimens from the Middle Devonian rocks of Ontario, Michigan and Ohio. He indicated that width of costae was not constant even within a specific population, and commented further that the number of costae and the length of interarea was dependent on the age and/or size of the specimen. He also noted that development of the median ridge in the sulcus and groove on the fold was not stable at all except in specimens from the Genshaw Formation and the Arkona Shale Formation. Based on his examination of growth lines on numerous specimens, Tillman (1964) determined that all the specimens described in previous publications achieved a mucronate form at a specific stage during their growth time and commented that, because cardinal extremities are not consistently preserved, width/length ratios were of limited value in this genus. Futhermore, he also found the height of the fold to decrease with an increase in the angle made by the plane of the commissure, and this angle itself varies widely. Mindful of the difficulties faced in classifying forms of *Mucrospirifer* on the basis of these attributes, Tillman (1964) used characters of fold and sulcus, the overall shape and the general proportions of the shell to ultimately assign all forms of *Mucrospirifer* from the Middle Devonian rocks of Ontario, Michigan and Ohio to two species: *M. mucronatus* and *M. thedfordensis*, asserting that *M. mucronatus* is distinguishable from *M. thedfordensis* by its broadly U-shaped sulcus with flattened floor and subangular edges, and a gently convex to flattened fold.

Welch (1991) studied the geographical variation and evolution of *Mucrospirifer* from Middle Devonian mudstones, calcareous shales, siltstones, sandstones, and limestones of Ontario, Michigan, New York, Pennsylvania, Maryland, and West Virginia through a stratigraphic interval spanning some 5-7 million years of geological history. Welch (1991) used the same criteria as did Tillman (1964) in attempting to identify individual species of *Mucrospirifer*, but used cluster analysis, polar ordination, and principal component analysis to further investigate the validity of the distinctions claimed by previous authors to define species within the genus. The verdict of this investigation was that specimens of *Mucrospirifer* within and among populations throughout the stratigraphic interval and geographic range covered in Welch's (1991) study exhibit continuous morphological variation, suggesting the occurrence of only a single polytypic species, *Mucrospirifer mucronatus*. He noted, however, that despite the lack of a strong correlation between morphology and lithology over the entire study area, an east-west trend of increasing roundness across New York State was apparent in his linear regression results. Furthermore, based on principal component analysis and linear regression, he found that there was no significant directional change in overall shape and thus drew a conclusion that this single polytypic species indicated its morphological stasis in the 5-7 million-year history.

The present author's examination of some 1220 complete specimens and 850 incomplete specimens of *Mucrospirifer* collected specifically for this study from the Middle Devonian Hamilton Group in southwestern Ontario, plus 23 complete specimens from contemporaneous strata of the Silica Formation of Ohio (donated by amateur fossil collectors Michael Topor and John Topor), supports the conclusions of Welch's (1991) study. As seen in Plates 2-19 through 2-23, considerable variation of external form is indeed obviously present in the collected specimens, to the extent that it is difficult to recognize any two specimens that are close to identical. Since the internal features have not been studied in previous work, the transverse serial sections (Figure 2-38 through 2-54) have been made to each sample in Plates 2-19 through 2-23. Like the external features emphasized by previous authors, the internal features such as dental plates, teeth, and spiralium show a continuous variation that support the diagnosis of a single polytypic species.

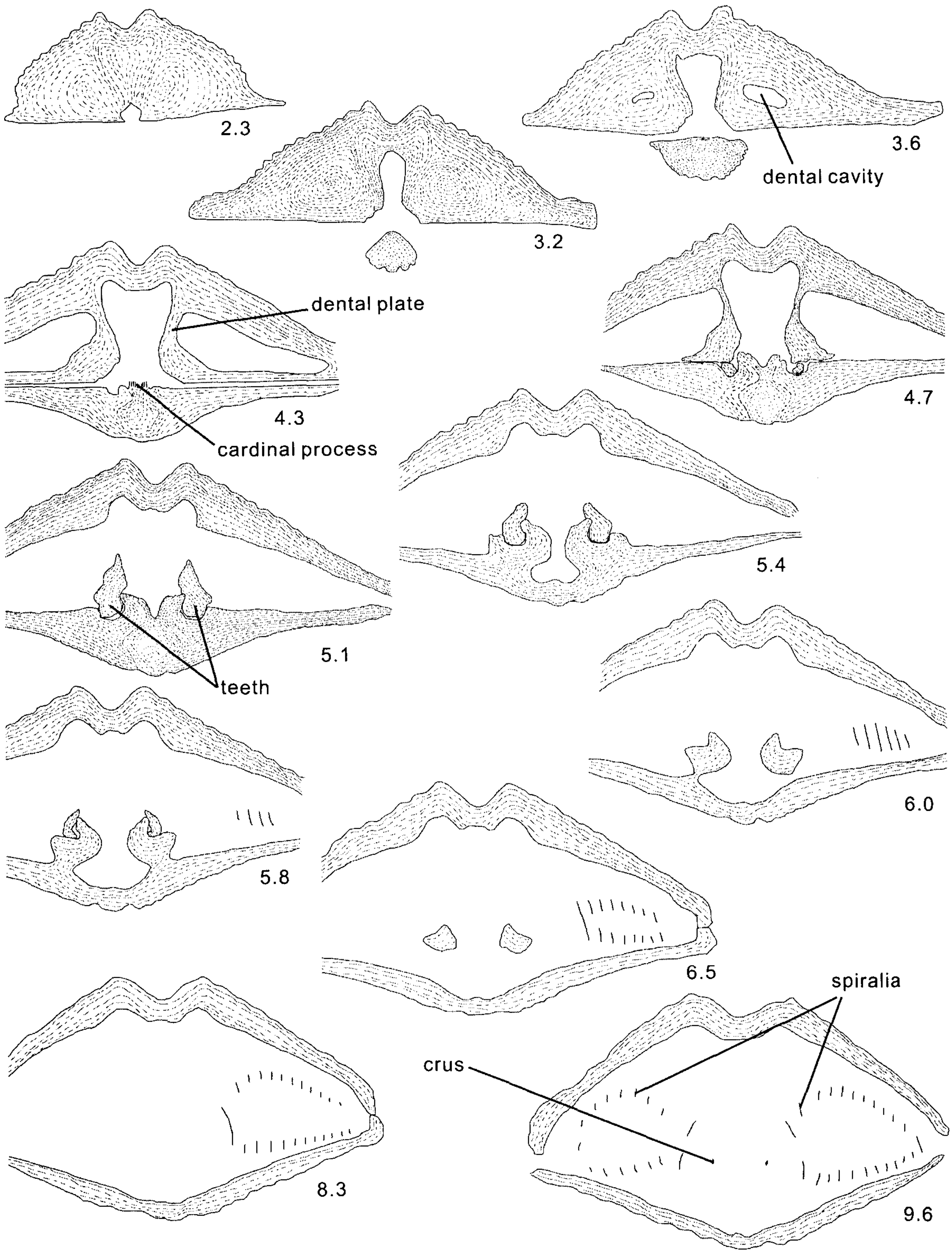


Fig. 2-38. Selected transverse serial sections of *Mucrospirifer mucronatus* (Conrad, 1841). W 2875. Golden Creek Submember, Petrolia Member, Widder Formation. Collecting locality 7. Distances in mm from posterior tip of ventral umbo. X2.5

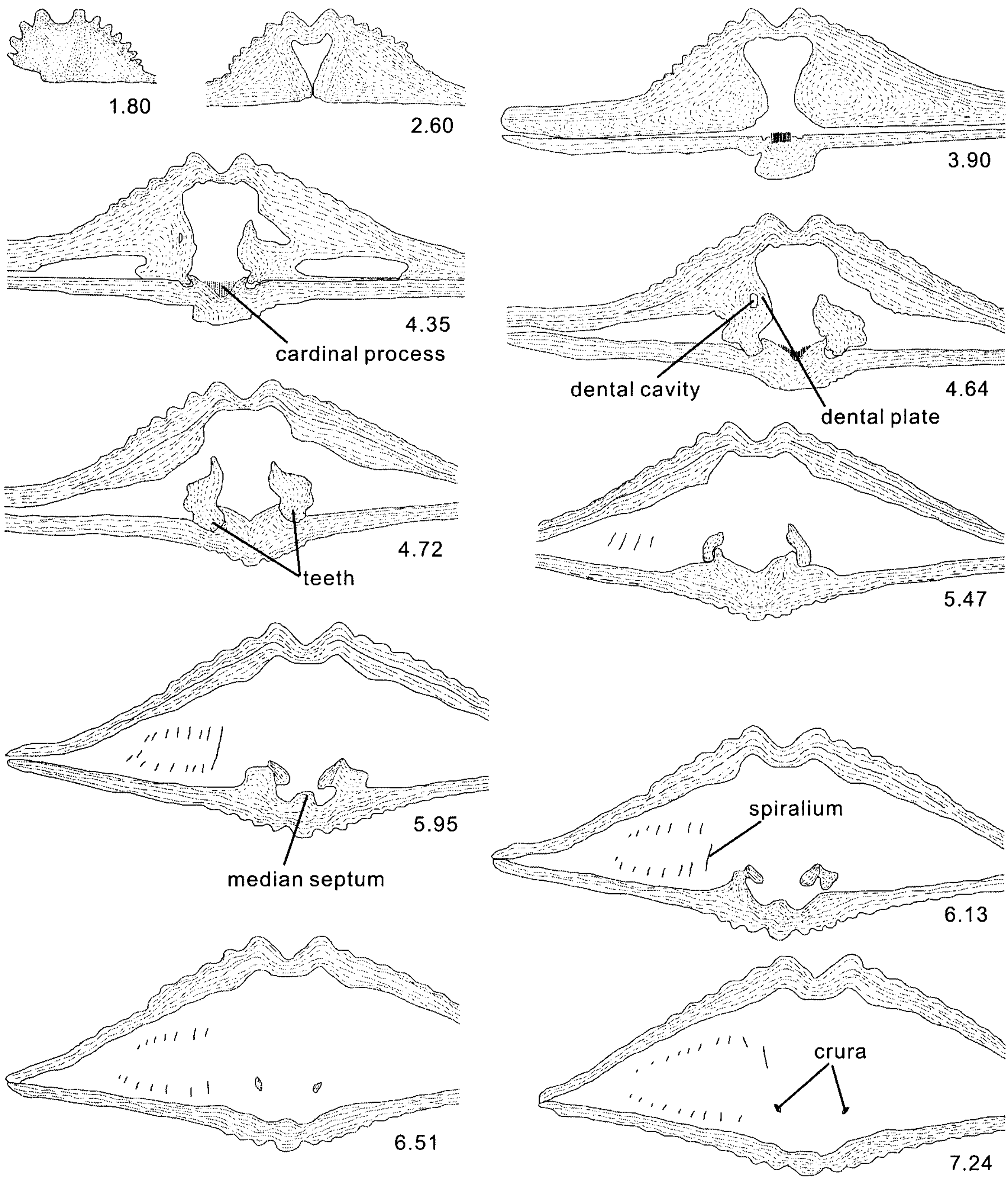


Fig. 2-39. Selected transverse serial sections of *Mucrospirifer mucronatus* (Conrad, 1841). W 2876. Golden Creek Submember, Petrolia Member,Widder Formation. Collecting locality 7. Distances in mm from posterior tip of ventral umbo. X2.5

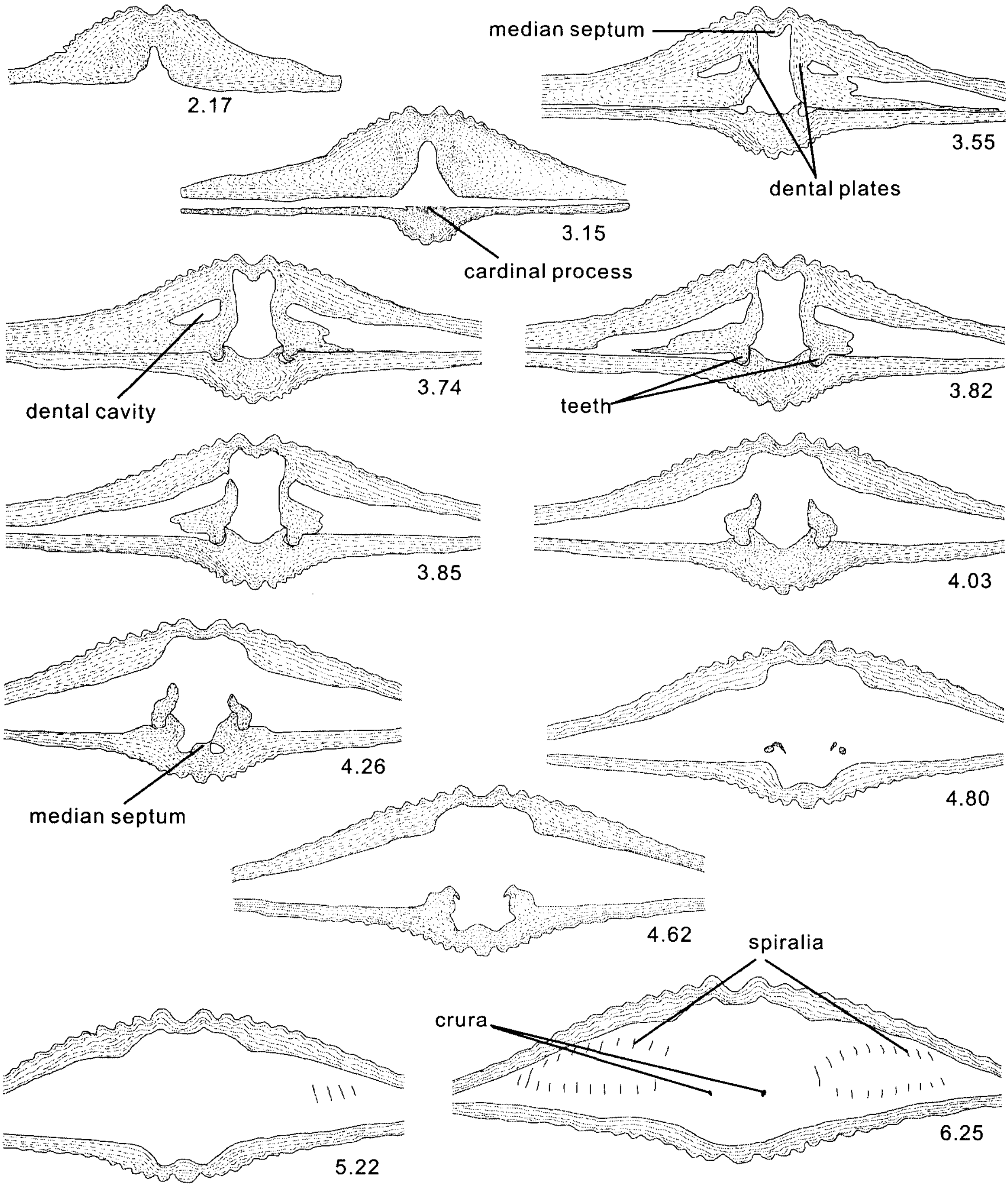


Fig. 2-40. Selected transverse serial sections of *Mucrospirifer mucronatus* (Conrad, 1841). W 2877. Golden Creek Submember, Petrolia Member,Widder Formation. Collecting locality 7. Distances in mm from posterior tip of ventral umbo. X2.5

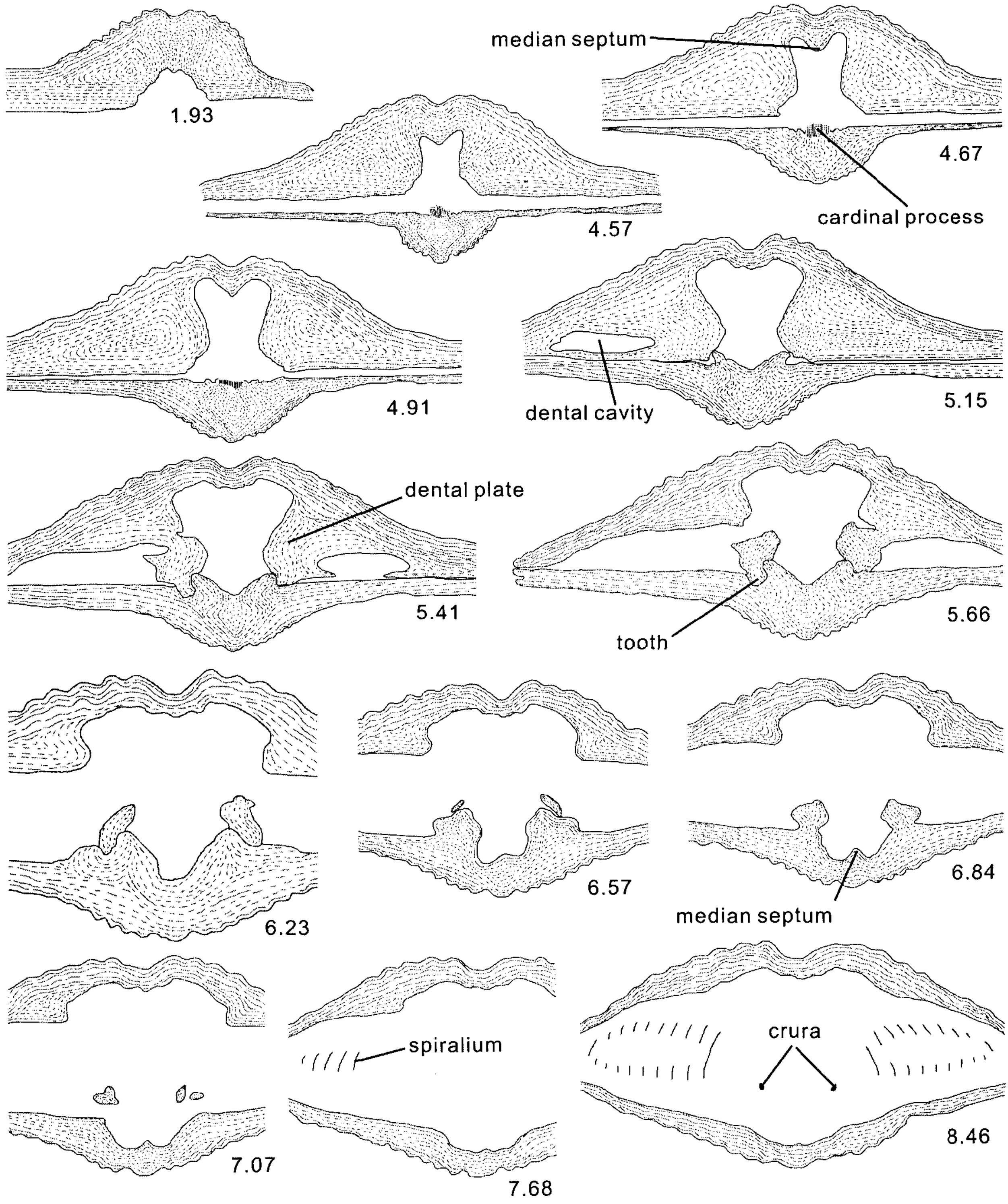


Fig. 2-41. Selected transverse serial sections of *Mucrospirifer mucronatus* (Conrad, 1841). W 2878. Golden Creek Submember, Petrolia Member, Widder Formation. Collecting locality 7. Distances in mm from posterior tip of ventral umbo. X2.5

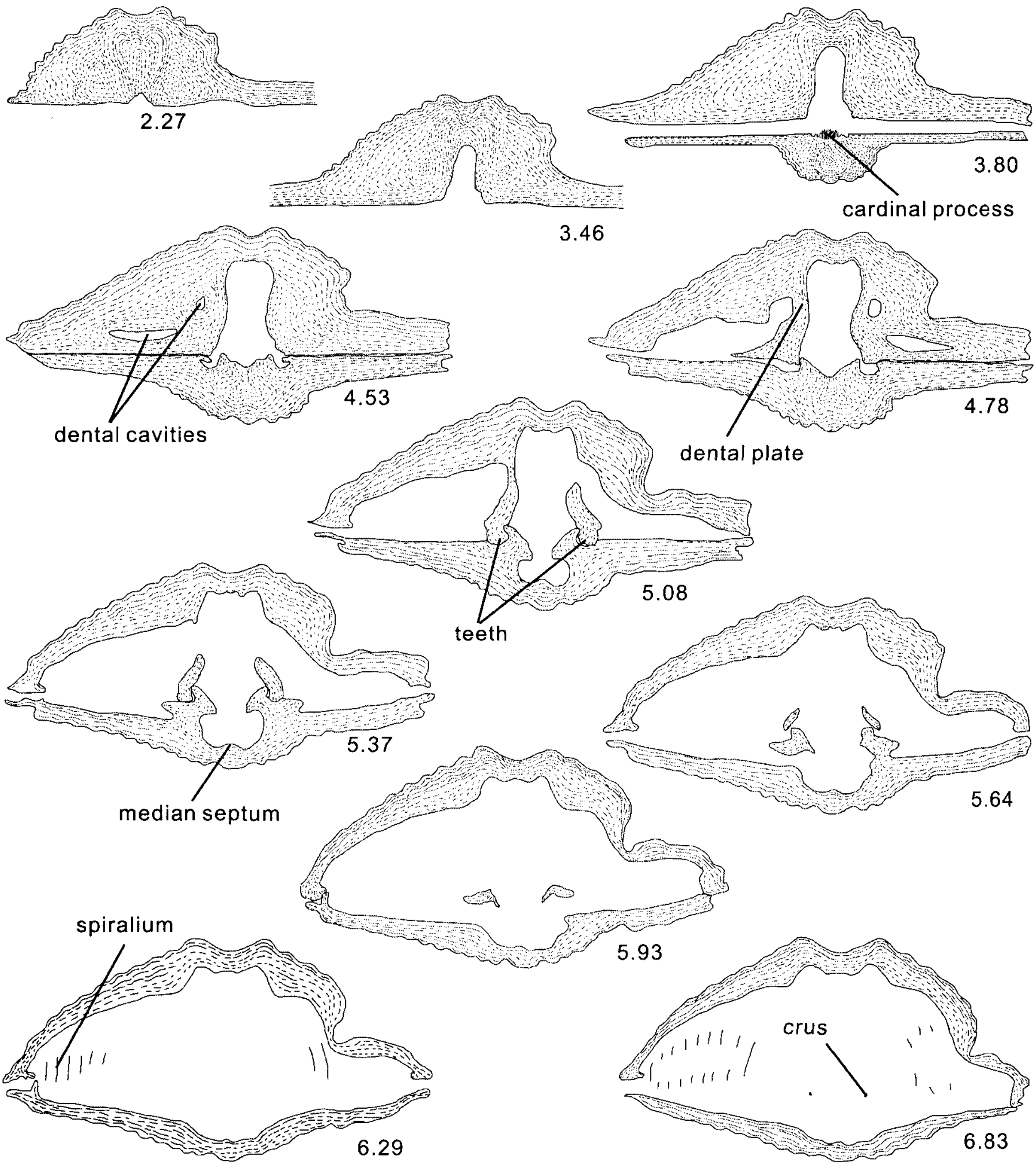


Fig. 2-42. Selected transverse serial sections of *Mucrospirifer mucronatus* (Conrad, 1841). W 2879. Thedford Member, Widder Formation. Collecting locality 3. Distances in mm from posterior tip of ventral umbo. X2.5

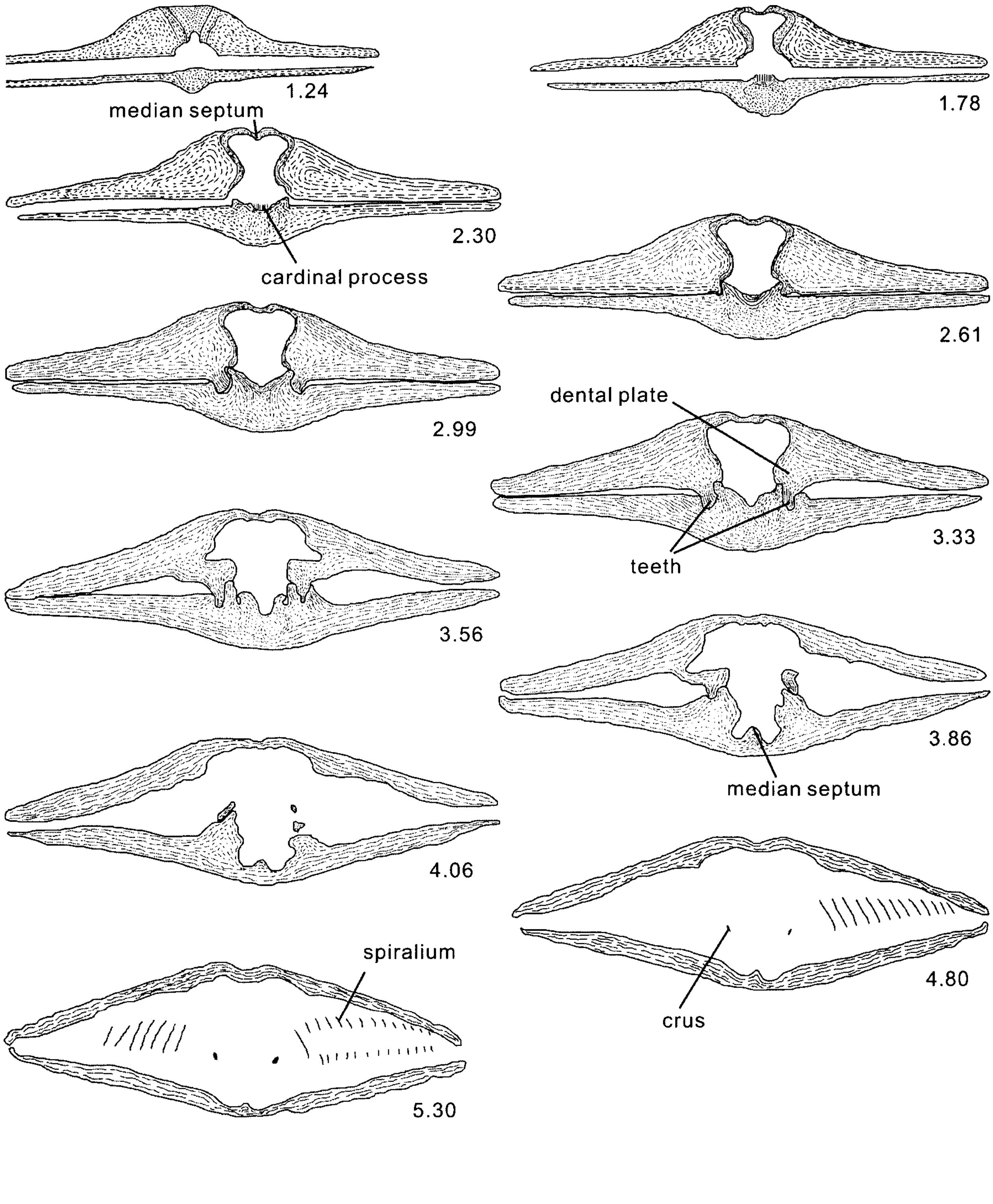


Fig. 2-43. Selected transverse serial sections of *Mucrospirifer mucronatus* (Conrad, 1841). W 2880. Stony Point Submember, Petrolia Member, Widder Formation. Collecting locality 8. Distances in mm from posterior tip of ventral umbo. X2.5

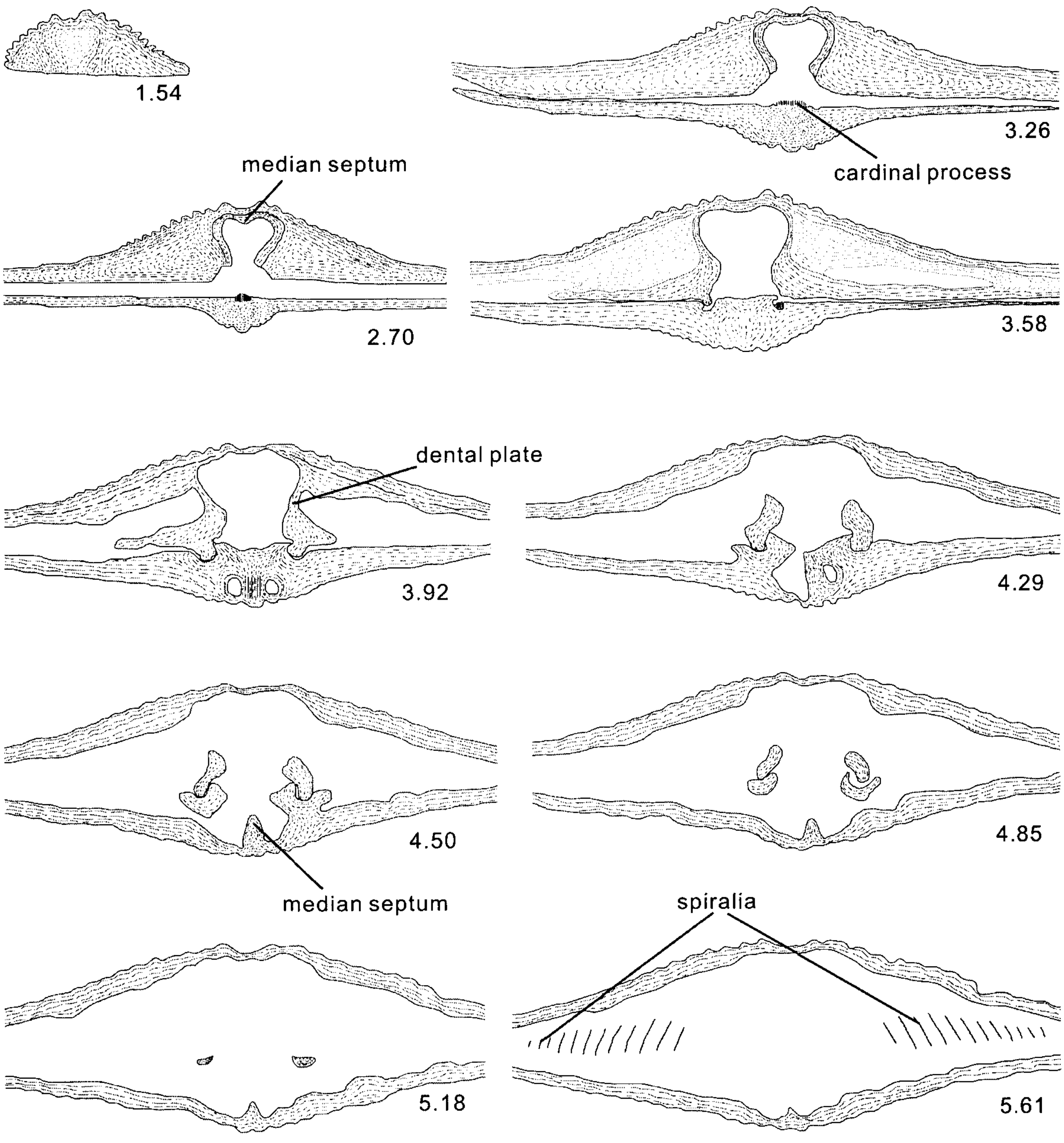


Fig. 2-44. Selected transverse serial sections of *Mucrospirifer mucronatus* (Conrad, 1841). W 2881. Arkona Shale. Collecting locality 10. Distances in mm from posterior tip of ventral umbo. X2.5

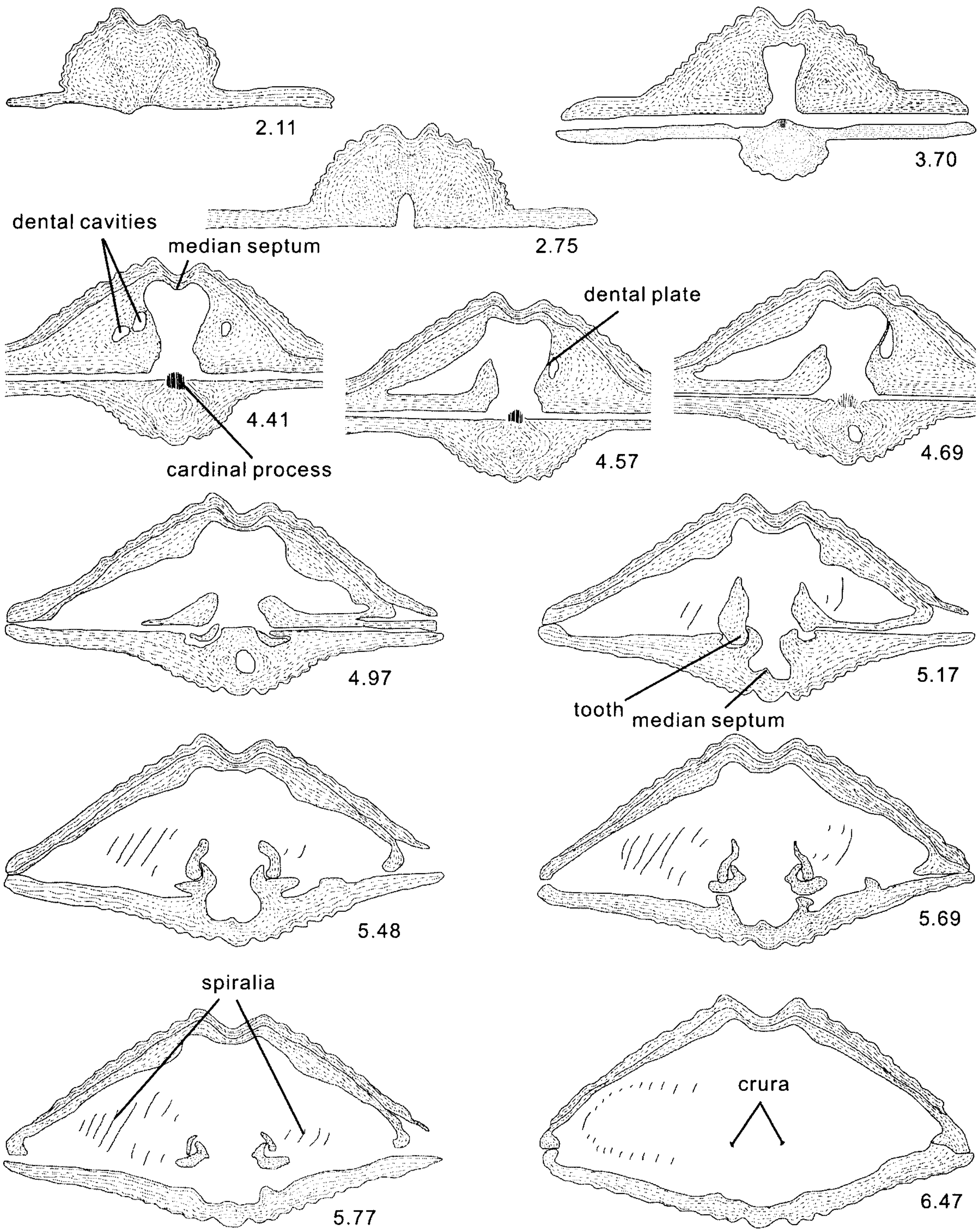


Fig. 2-45. Selected transverse serial sections of *Mucrospirifer mucronatus* (Conrad, 1841). W 2882. Rock Glen Submember, Petrolia Member,Widder Formation. Collecting locality 10. Distances in mm from posterior tip of ventral umbo. X2.5

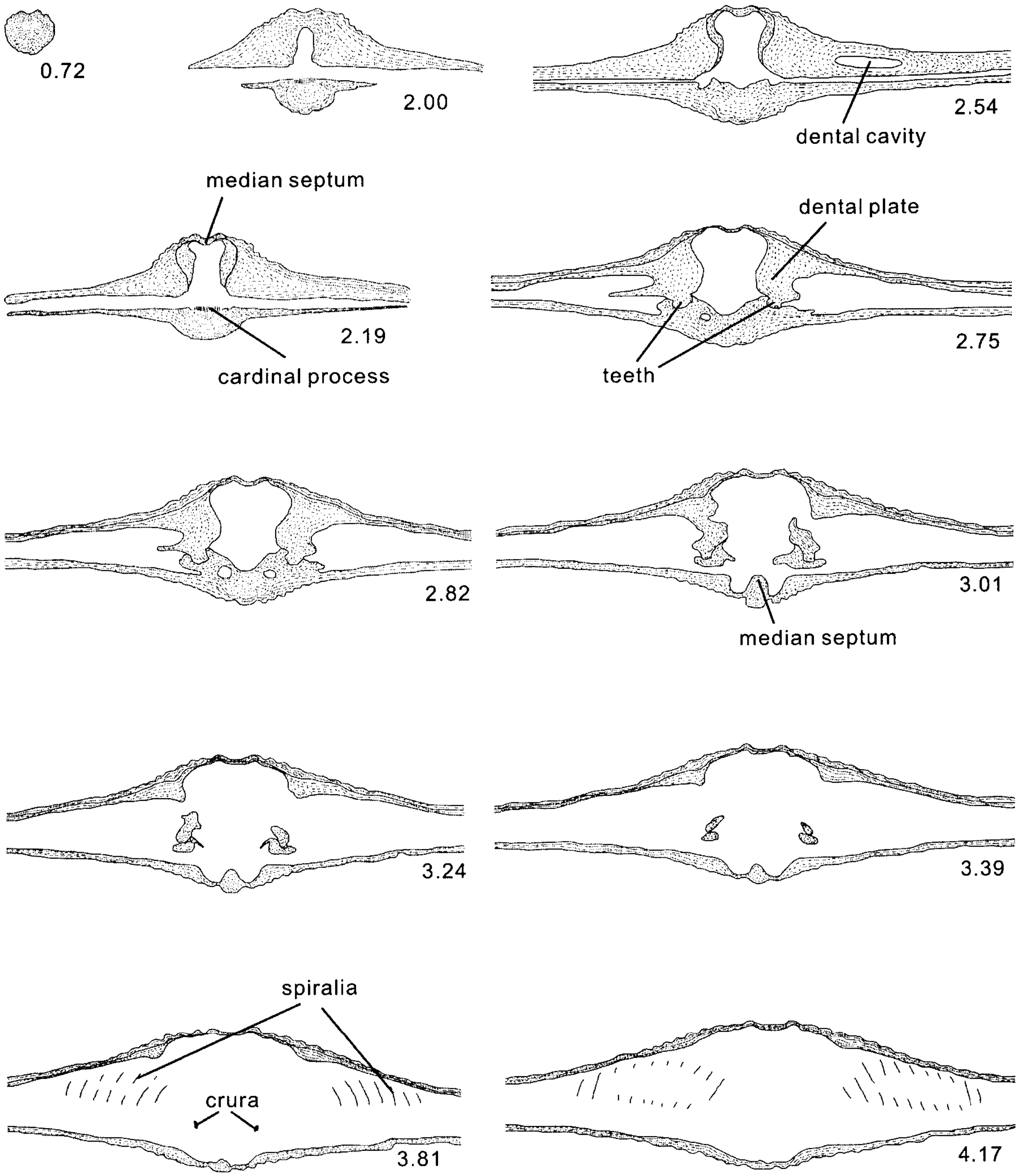


Fig. 2-46. Selected transverse serial sections of *Mucrospirifer mucronatus* (Conrad, 1841). W 2883. Arkona Shale. Collecting locality 2. Distances in mm from posterior tip of ventral umbo. X2.5

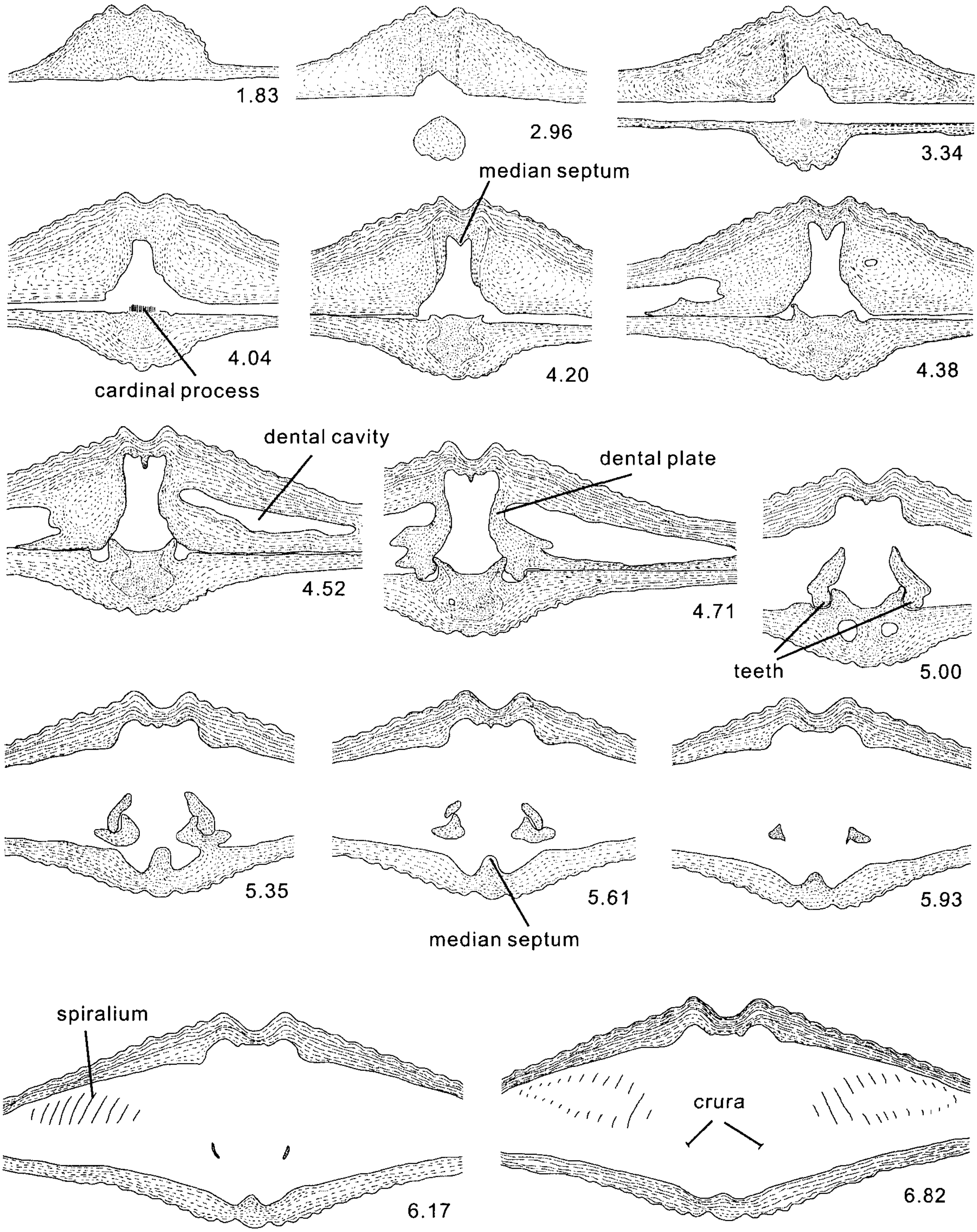


Fig. 2-47. Selected transverse serial sections of *Mucrospirifer mucronatus* (Conrad, 1841). W 2884. Thedford Member, Widder Formation. Collecting locality 3. Distances in mm from posterior tip of ventral umbo. X2.5

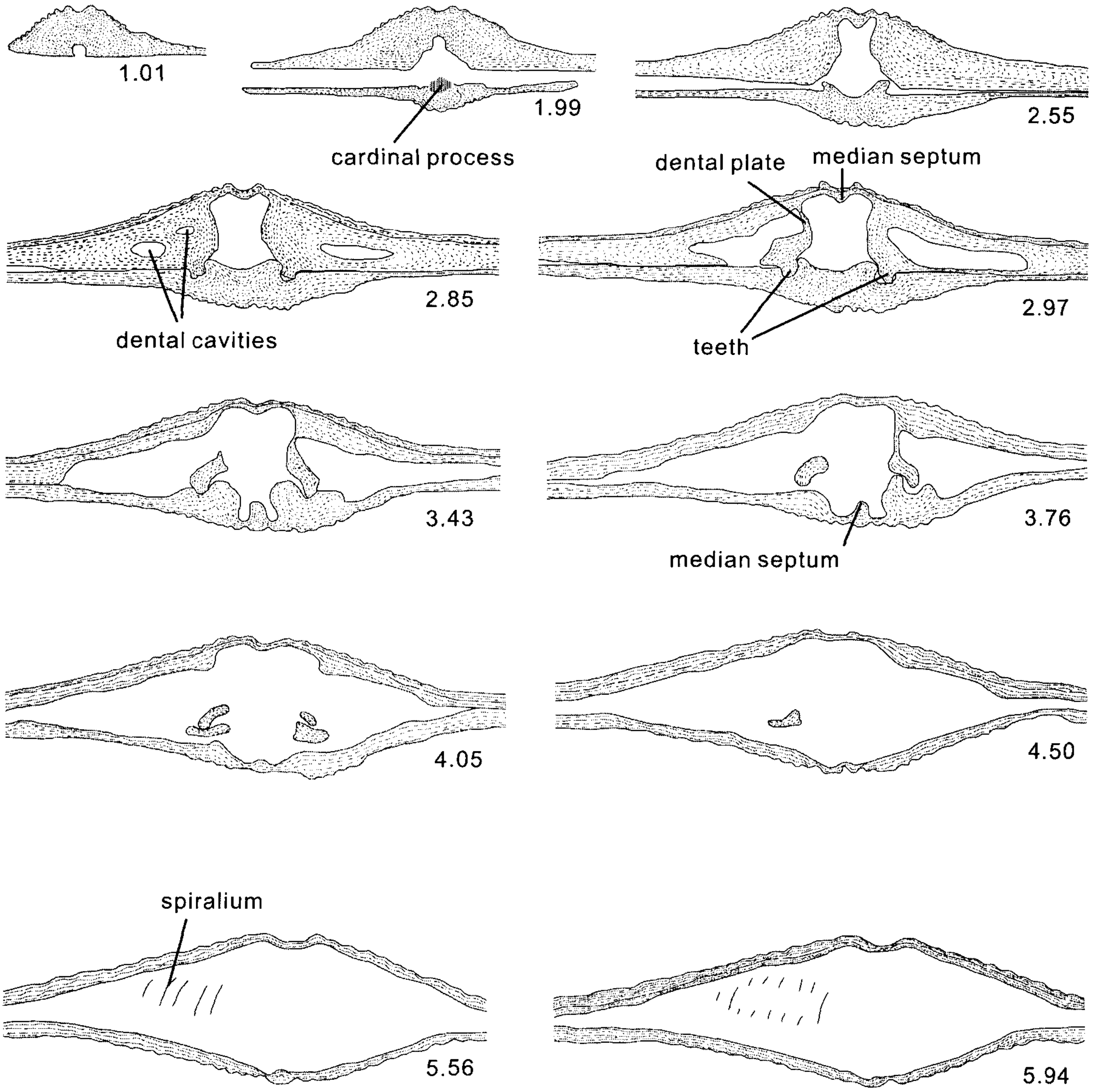


Fig. 2-48. Selected transverse serial sections of *Mucrospirifer mucronatus* (Conrad, 1841). W 2885. Arkona Shale. Collecting locality 10. Distances in mm from posterior tip of ventral umbo. X2.5

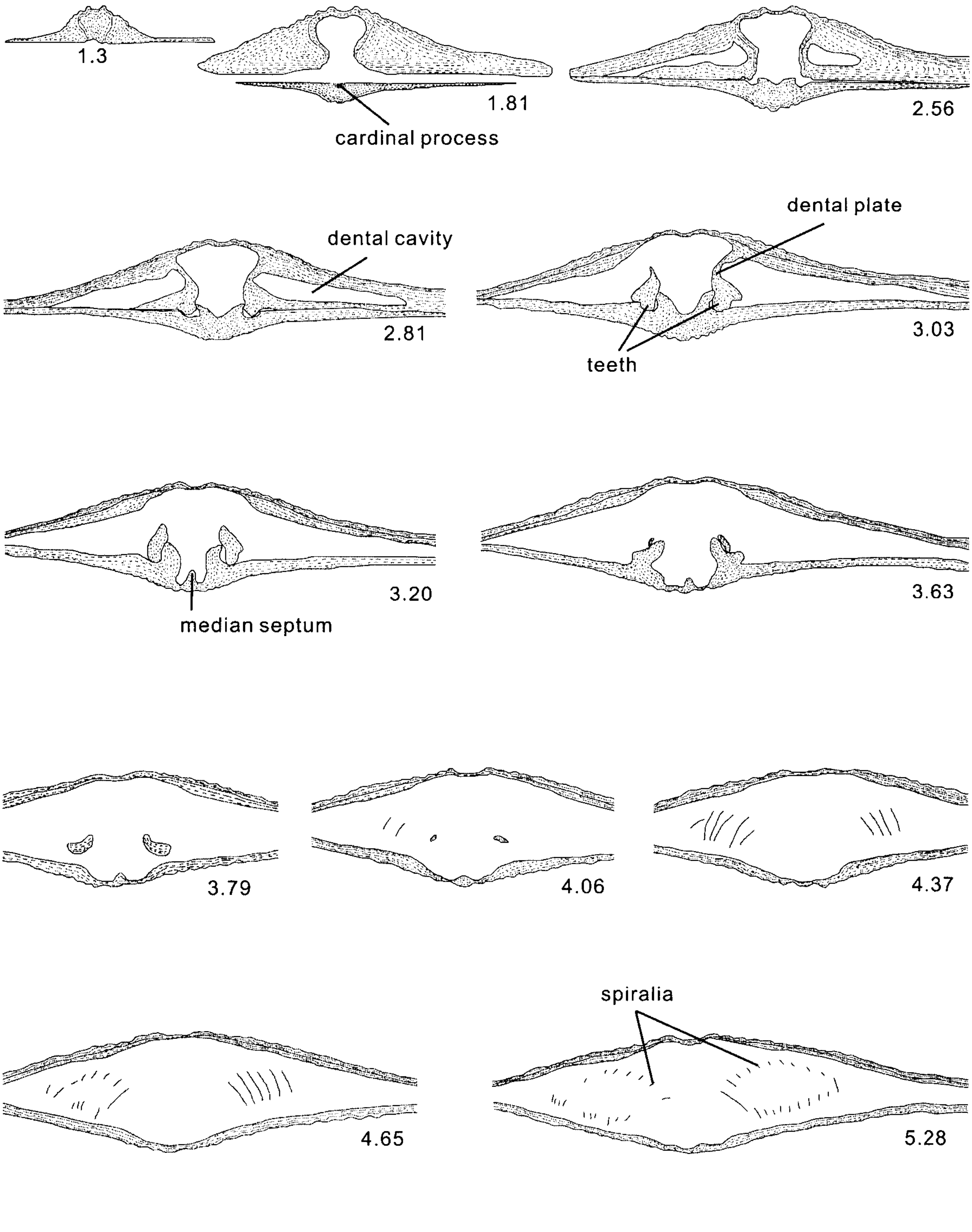


Fig. 2-49. Selected transverse serial sections of *Mucrospirifer mucronatus* (Conrad, 1841). W 2886. Arkona Shale . Collecting locality 10. Distances in mm from posterior tip of ventral umbo. X2.5

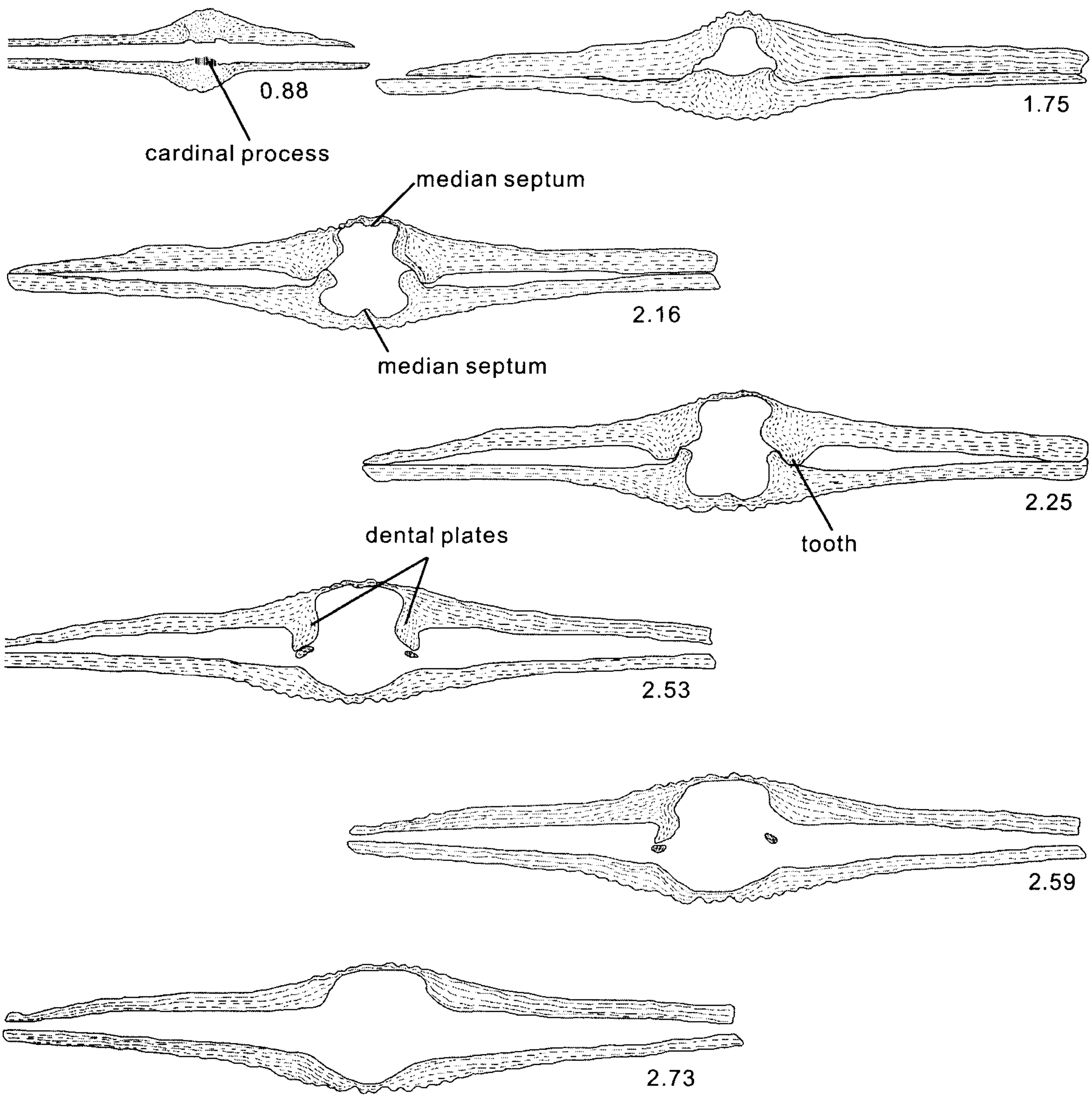


Fig. 2-50. Selected transverse serial sections of *Mucrospirifer mucronatus* (Conrad, 1841). W 2887. Arkona Shale. Collecting locality 2. Distances in mm from posterior tip of ventral umbo. X3.0

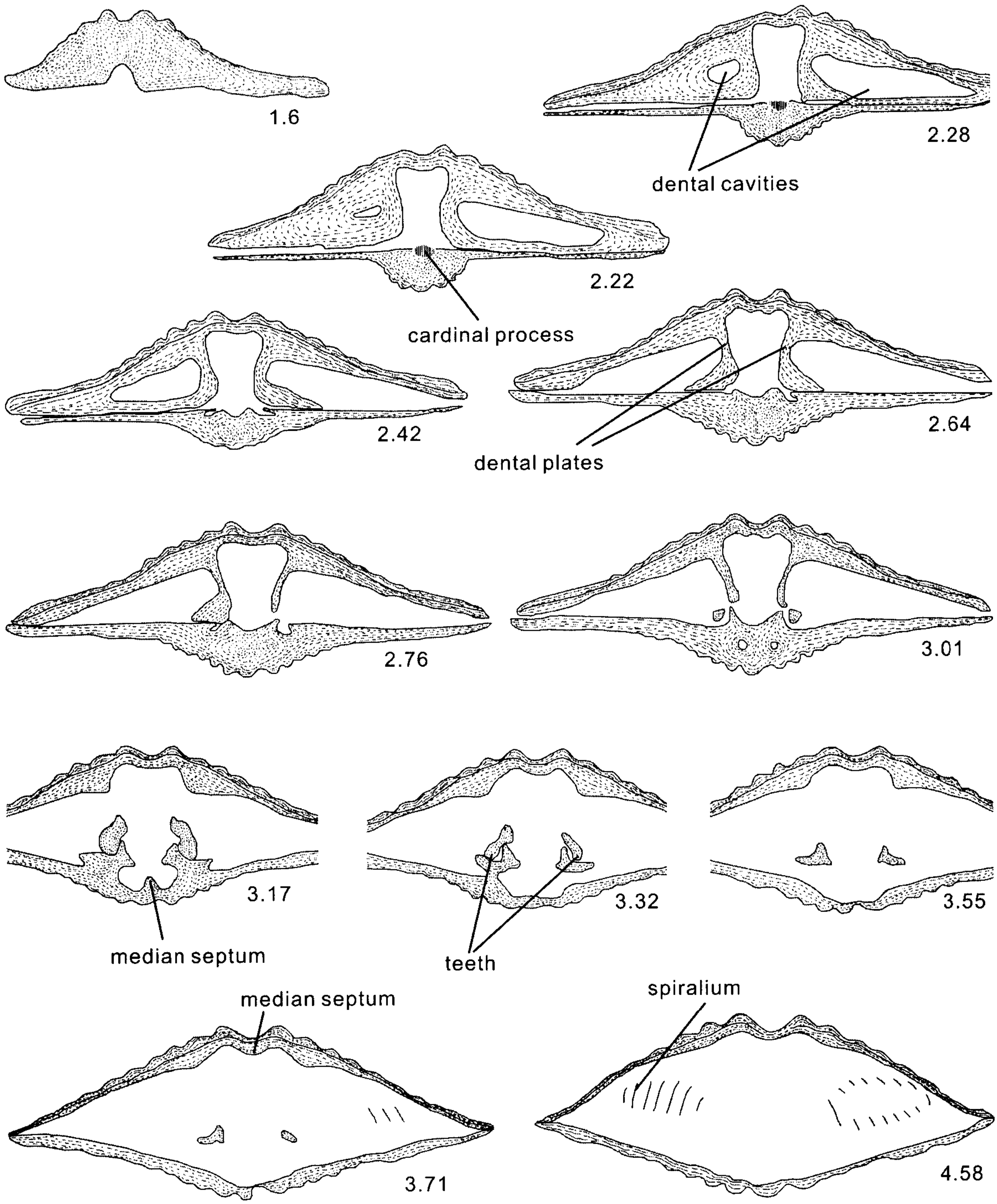


Fig. 2-51. Selected transverse serial sections of *Mucrospirifer mucronatus* (Conrad, 1841). W 2888. Rock Glen Submember,Petrolia Member,Widder Formation. Collecting locality 10. Distances in mm from posterior tip of ventral umbo. X3.5

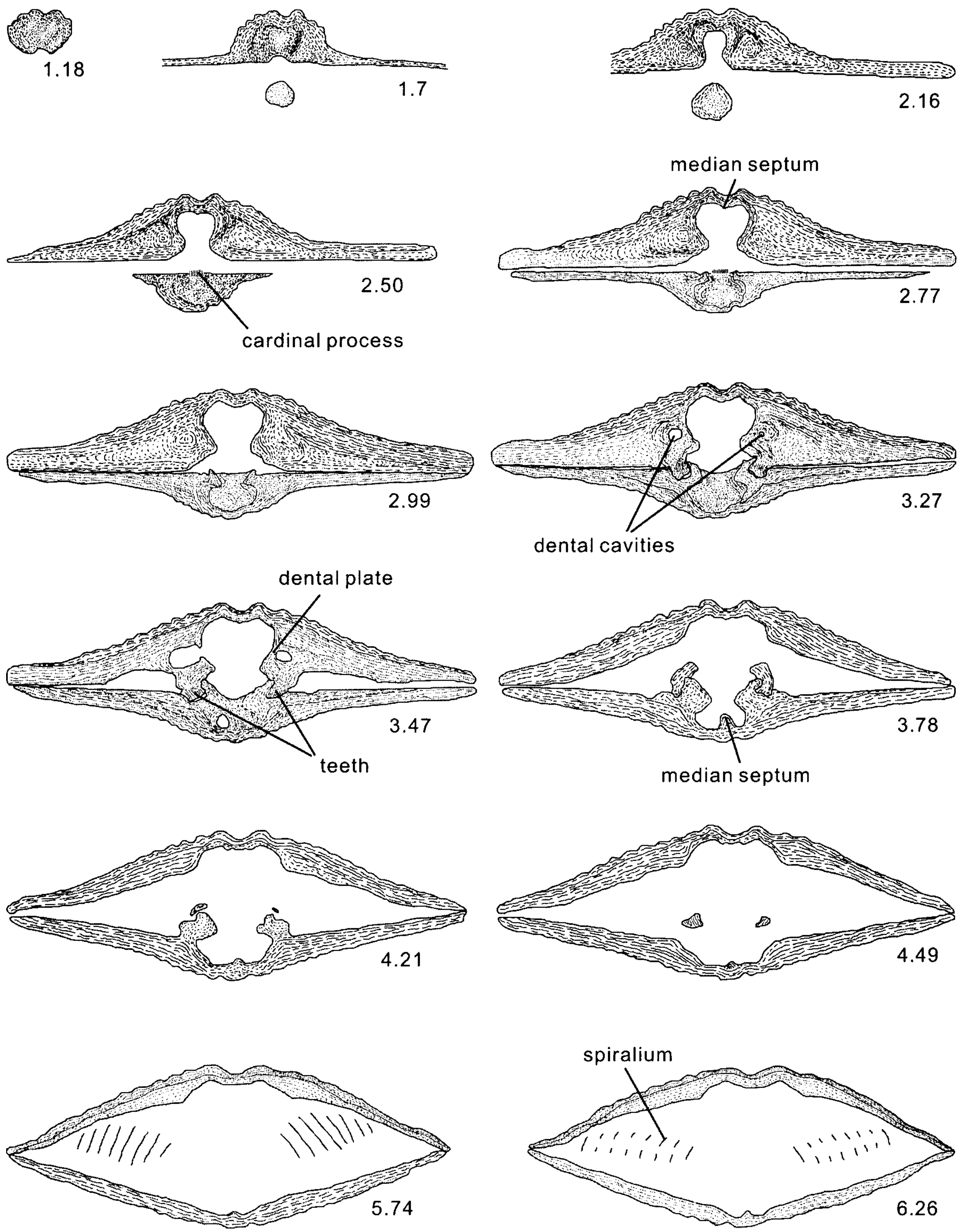


Fig. 2-52. Selected transverse serial sections of *Mucrospirifer mucronatus* (Conrad, 1841). W 2889. Thedford Member, Widder Formation. Collecting locality 3. Distances in mm from posterior tip of ventral umbo. X2.5

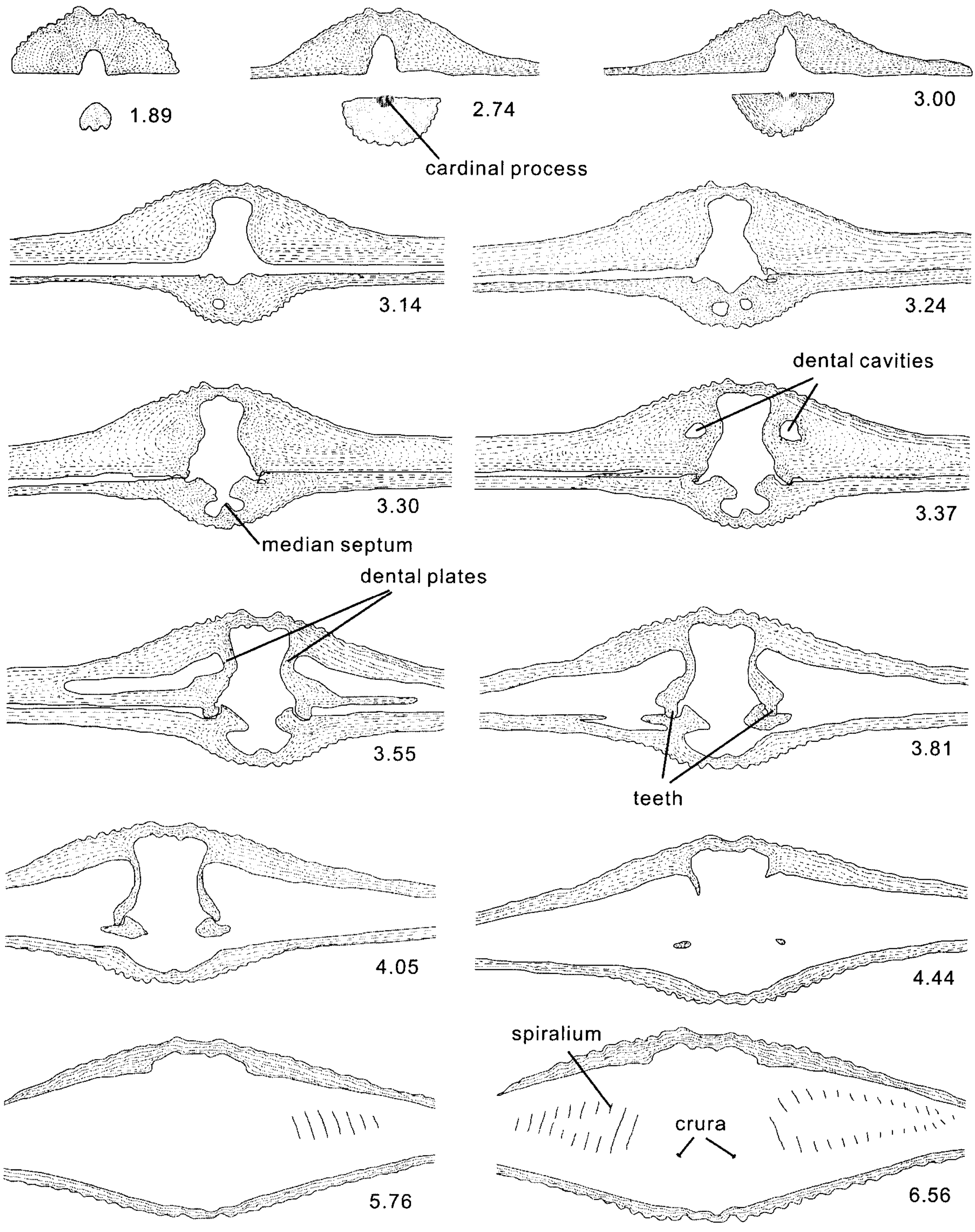


Fig. 2-53. Selected transverse serial sections of *Mucrospirifer mucronatus* (Conrad, 1841). W 2890. Silica Formation. Lucas County, Ohio. Distances in mm from posterior tip of ventral umbo. X2.5

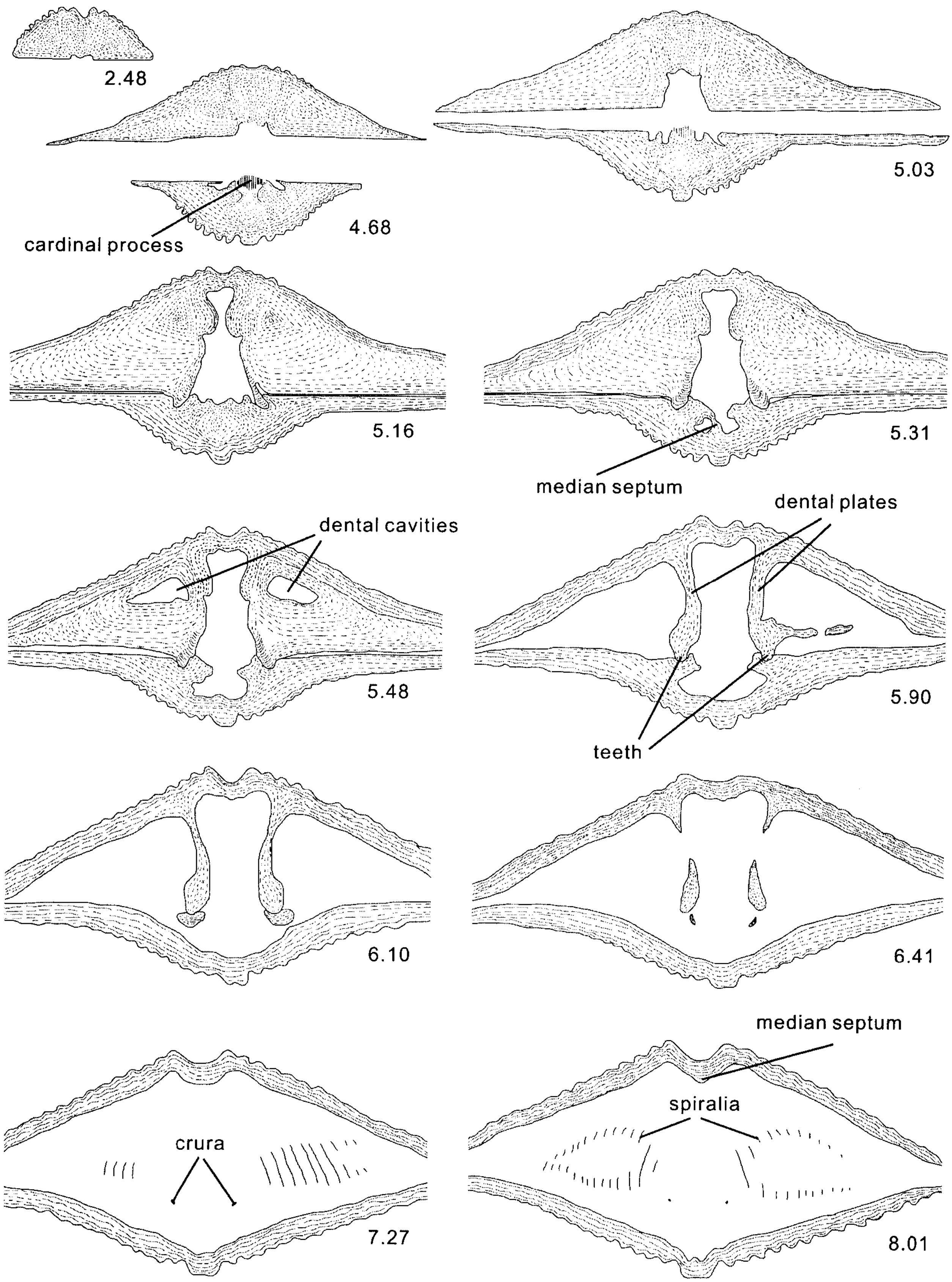


Fig. 2-54. Selected transverse serial sections of *Mucrospirifer mucronatus* (Conrad, 1841). W 2891. Silica Formation. Lucas County, Ohio. Distances in mm from posterior tip of ventral umbo. X2.5

Superfamily RETICULARIOIDEA Waagen, 1883

Family ELYTHIDAE Frederiks, 1924

Subfamily ELYTHINAE Frederiks, 1924

Genus *Elita* Frederiks, 1918

Type species: *Delthyris fimbriata* Conrad, 1842, Oriskany Sandstone (Early Devonian), Tinkers's falls, Courtland County, New York.

Elita fimbriata (Conrad, 1842)

Pl. 2-2, figs. 11-15

1842 *Delthyris fimbriata* Conrad, p. 263.

1858 *Spirifer fimbriatus*; Hall, p. 505, pl. 4, fig. 5.

1867 *Spirifera fimbriata*; Hall, p. 214, pl. 33, figs. 1-11.

1868 *Spirifer compactus* Meek, p. 102, pl. 14, fig. 11.

1868 *Spirifer (Martinia) richardsoni* Meek, p. 104, pl. 14, fig. 2.

1883 *Spirifera fimbriata*; Hall, pl. 61, figs. 17-22.

1883 *Spirifera conradana* Miller, p. 312.

1884 *Spirifera (Martinia) andifera* Walcott, pl. 3, figs. 3-6; and pl. 14, fig. 11.

1889 *Spirifera (Martinia) fimbriata*; Whiteaves, p. 124.

1889 *Spirifera conradana*; Nettelroth, p. 110, pl. 7, figs. 11-13.

1891 *Spirifera (M.) richardsoni*; Whiteaves, p. 226.

1892 *Spirifera (M.) richardsoni*; Whiteaves, p. 287, pl. 37, fig. 7.

1892 *Spirifera fimbriata*; Whiteaves, p. 286.

1894b *Spirifer fimbriatus*; Hall & Clarke, p. 17, 20, 21, 33, and 37, pl. 36, figs. 17-22; pl. 38, figs. 9 and 10.

1897 *Reticularia fimbriata*; Schuchert, p. 342.

1898 *Reticularia fimbriata*; Whiteaves, p. 394.

1902 *Reticularia fimbriata*; Shimer & Grabau, p. 183.

1915 *Reticularia fimbriata*; Stauffer, p. 111.

1944 *Elytha fimbriata*; Shimer & Shrock, p. 327, pl. 126, figs. 1-3.

1956 *Elytha fimbriata*; Wells, p. 750.

1958 *Elytha fimbriata*; Stumm & Wright, p. 106.

1959b *Elytha fimbriata*; Boucot, p. 745, pl. 93, figs. 14-16.

2006 *Elita fimbriata*; Zhuravlev, et al., p. 751.

Types. Conrad's (1842) original description was based on specimens from the Lower Devonian Oriskany Sandstone, Tinkers's Falls, Courtland County, New York. He did not designate a holotype or provide specimen illustrations. Original specimens cannot be traced from previous references.

Description. Shell medium-sized, subelliptical, transversely extended; the maximum width at mid-length; cardinal extremities rounded; flanks with low, rounded plications (5-7 in number per flank), crossed by relatively thick, imbricating growth lamellae, studded with moderately coarse marginal biramous spines.

Ventral umbonal area strongly convex, forming an apical angle of 89°- 94°; ventral interarea moderately high (2.8-3.2 mm high), apsacline; delthyrium large; sulcus well-defined, shallow and rounded, originating at apex and widening anteriorly; beak small and incurved.

Ventral interior with long dental plates and median septum.

Dorsal valve moderately convex; fold low but well defined, beginning from apex and widening anteriorly; dorsal beak small, slightly arched over the sublinear interarea.

Dorsal interior with ctenophoridium; ctenophoridium inconsistently bilobed; strong socket plates supported by short septa; median septum absent.

Material. Total 3 complete specimens and 13 incomplete specimens.

Occurrence. Coral Unit, Hungry Hollow Member, Widder Formation; Arkona-Thedford-Ipperwash area, southwestern Ontario.

Discussion. Elita formosensis (Fagerstom, 1961) (Fagerstom, 1961, p. 30-31, pl. 10, figs. 21-26) from the Middle Devonian Formosa Reef Limestone of southwestern Ontario differs from *Elita fimbriata* (Conrad, 1842) in its subpentagonal outline, relatively fewer and prominent costae on flanks of the shell (2-4 in number per flank), and higher dorsal fold. *E.* cf. *E. subundifera* (Meek & Worthen, 1868) from the Middle Devonian Milwaukee Formation of southeastern Wisconsin (Griesemer, 1965, p. 285, pl. 5, figs. 20-21) differs from *E. fimbriata* in its subpentagonal outline, more convex dorsal valve, deeper sulcus and higher length/width ratio. Although *E. fimbriata* resembles *E. lemoni* Norris 1993 from the Middle Devonian rocks of the unnamed island on Abitibi River of the Moose River Basin of north Ontario (Norris, 1993, p. 63-65, pl. 14, figs. 1-32; pl. 15, figs. 1-10) in shape and form of plications, it is distinguished from the latter species by its much larger adult size, longer marginal biramous spines (rather than short single spines), and the smaller number of plications on the flanks of shell (Norris, 1993, p. 64).

Order SPIRIFERINIDA Ivanova, 1972

Suborder CYRTINIDINA Carter & Johnson, 1994

Superfamily CYRTINOIDEA Frederiks, 1911

Family CYRTINIDAE Frederiks, 1911

Genus *Cyrtina* Davidson, 1859

Type species: *Calceola heteroclita* Defrance, 1828, western Europe (the exact horizon and locality unknown), Middle Devonian.

Cyrtina angularis Ehlers & Wright, 1975

Pl. 2-24, figs. 11-15; Table 2-25; Fig. 2-55; Fig. 2-56

1867 *Cyrtina hamiltonensis*; Hall, p. 268, pl. 44, figs. 38-40, 41, 42, ?43, 44, 48, and 49.

1894b *Cyrtina hamiltonensis*; Hall & Clarke, p. 46, pl. 28, figs. 23, 24, ?26, 27, 28, ?33, 43, 45, 46 and 53.

1975 *Cyrtina angularis* Ehlers & Wright, p. 154-155, pl. 1, figs. 1-13; pl. 4, figs. 1-28.

Types. Holotype UMMP 61509, Thedford Member, Widder Formation, Middle Devonian Hamilton Group, Paisley's Quarry, near Thedford, Lambton County, Ontario.

Description. Shell medium-sized, triangular-hemipyramidal, ventribiconvex; the maximum width along hinge line; hinge line straight; cardinal extremities slightly extended in some specimens; surface of shell marked by simple rounded costae (mainly 5-6 in number per flank, rarely 7-8 in number per flank), crossed by fine and weak growth lamellae; surfaces of costae, fold, and sulcus covered by minute spinules; anterior commissure uniplicate;

Ventral valve moderately convex; ventral sulcus deep, subangular, with a median depression; beak incurved; some specimens with twisted beaks; interarea wider than high, slightly concave; delthyrium narrow, partly closed by convex pseudodeltidium, bearing a relatively large oval foramen close to apex; fine, horizontal growth lines present in ventral interarea.

Ventral interior with obvious primary shell and secondary shell; spondylium well-developed, bearing tichorhinum, supported by long median septum; dental plates thin, long, divergent; hinge teeth sub-rectangular.

Dorsal valve slightly convex, subrectangular in outline; dorsal fold rounded and relatively wide, with a shallow median depression; dorsal interarea linear.

Dorsal interior with bilobed cardinal process; sockets relatively shallow, bounded by prominent inner socket ridges; anteriorly, dorsal median septum incipient (Figure 2-55).

Material. Total 92 complete specimens and 34 incomplete specimens.

Occurrence. Widder Formation; Arkona-Thedford-Ipperwash area, southwestern Ontario.

Discussion. Cyrtina southworthi Ehlers & Wright, 1975, which is absent in the present author's collection, is from upper part of the Widder Formation (Ehlers and Wright, 1975). *C. angularis* is distinguishable from *C. southworthi* by its larger size and its median depressions on the fold and sulcus (Ehlers and Wright, 1975). *C. angularis* is distinguished from *C. hamiltonensis* (Hall, 1857) by its larger size, smaller number of costae, and deeper subangular sulcus. A fold with shallow median depression is present in most specimens of *C. angularis* while such median depression on fold is absent in *C. hamiltonensis* (Hall, 1857) (Ehlers and Wright, 1975, p. 155). *C. umbonata alpenensis* Hall & Clarke, 1894 (Hypotype UMMP 57597, the Museum of Paleontology, the

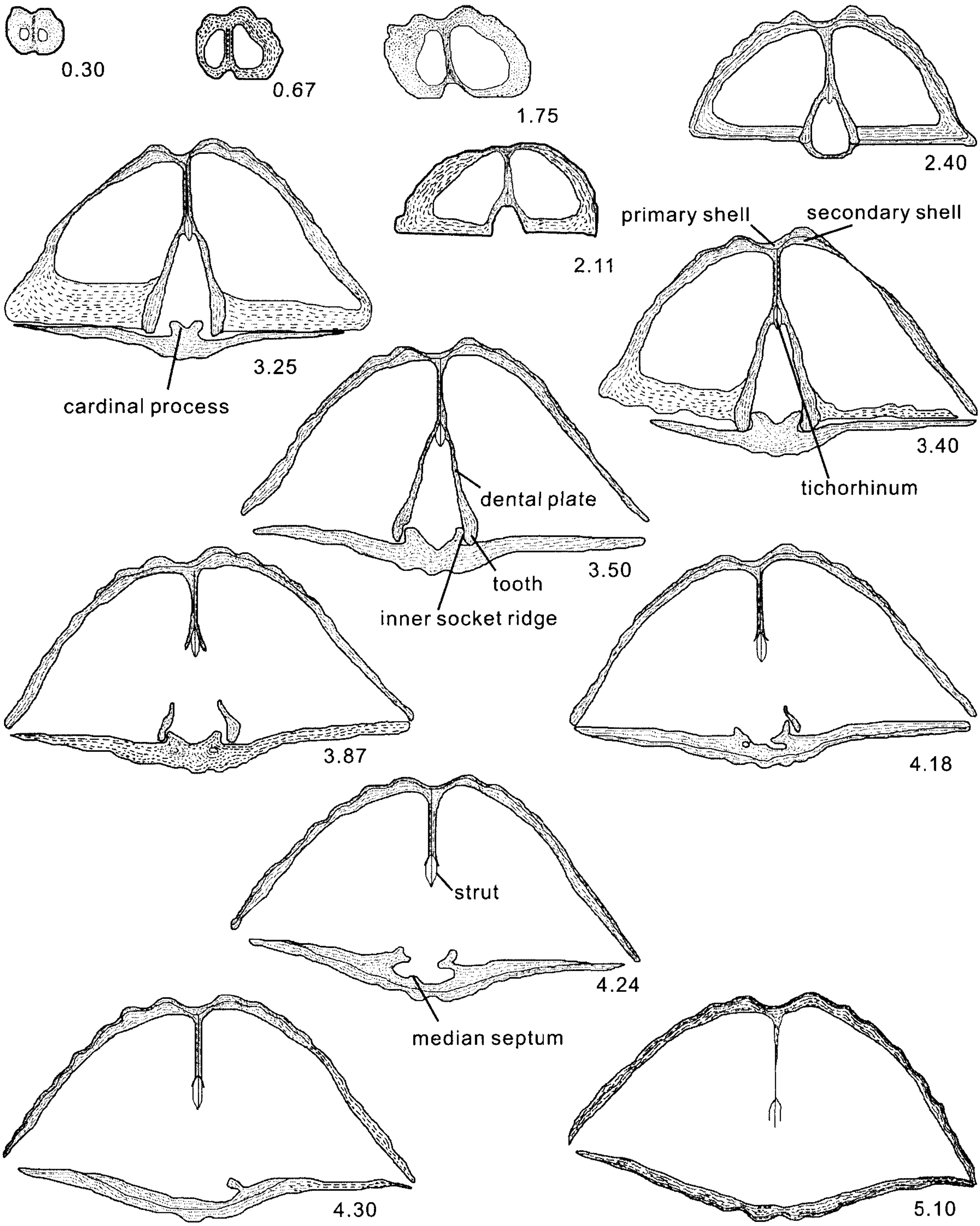


Fig. 2-55. Selected transverse serial sections of *Cyrtina angularis* Ehlers & Wright, 1975. W 2867. Golden Creek Submember, Petrolia Member, Widder Formation. Collecting locality 7. Distances in mm from posterior tip of ventral umbo. X4.5

	W	L	T	L/W	T/W
MEAN	15.04	11.21	8.35	0.75	0.56
STD	2.26	1.76	1.24	0.06	0.04
MIN	9.64	6.98	5.31	0.63	0.47
MAX	18.34	13.92	10.39	0.90	0.68
N	21	21	21	21	21

Table 2-25. Statistical data of shell dimensions (mm) for complete specimens of *Cyrtina angularis* Ehlers & Wright, 1975, sample from Collecting locality 4, Rock Glen Submember, Petrolia Member, Widder Formation.

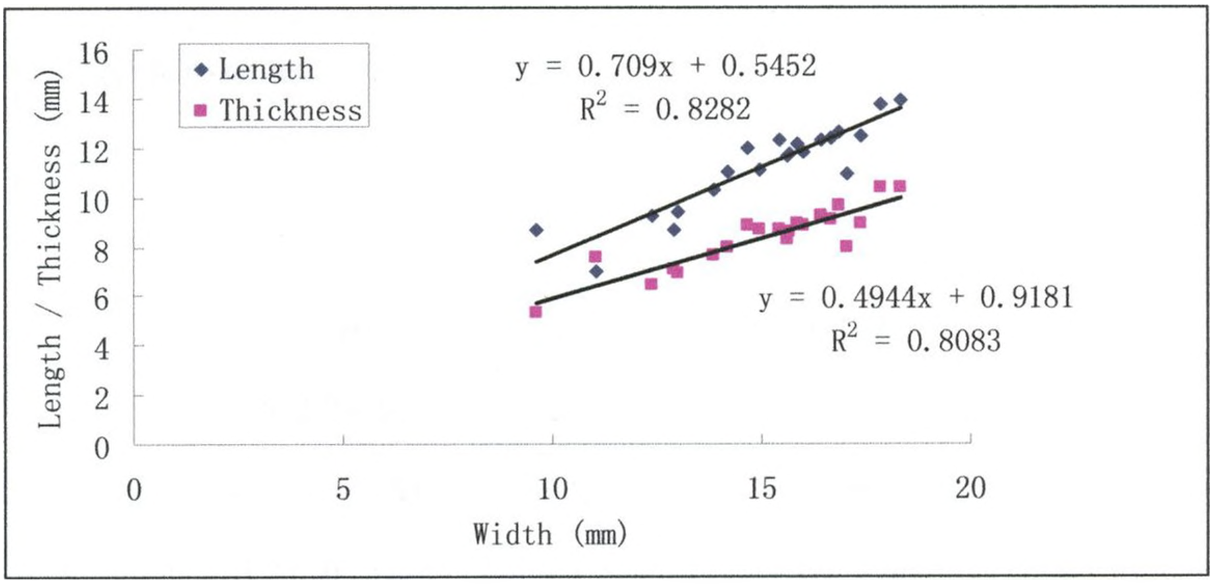


Fig. 2-56. Length-width and thickness-width graphs for complete specimens of *Cyrtina angularis* Ehlers & Wright, 1975, sample from Collecting locality 4, Rock Glen Submember, Petrolia Member, Widder Formation.

University of Michigan) from the Genshaw Formation of the Middle Devonian Traverse Group of Michigan differs from *C. angularis* in that the former has a subrectangular outline (versus the triangular-hemipyramidal outline that is typical of *C. angularis*). Also, *C. angularis* is less robust, smaller, has fewer costae in proportion to overall shell size, and has a much less curved interarea than *C. umbonata alpenensis*. *C. alpenensis alpenensis* Hall & Clark, 1895 from the Killians Member of the Genshaw Formation and Norway Point Formation in the Traverse Group of Michigan (Keyes and Pitrat, 1978, p. 222-224, pl. 1, figs. 1-5; text-figs. 1A, B, 2, 3) differs from *C. angularis*, in its larger size, subovate outline, more curved interarea and a larger and smoother umbonal area. *C. triquetra* (Hall, 1858) from the Middle Devonian Milwaukee Formation of southeastern Wisconsin (Griesemer, 1965, p. 288, pl. 6, figs. 7-9) differs from *C. angularis* (Table 2-25) in its smaller size (average width: 10.1 mm; average length: 7.1 mm; average thickness: 7.2 mm), lower length/width ratio (0.70), higher thickness/width ratio (0.71), greater number of costae (6-9 on each flank), and lack of minute spinules on the surface.

Cyrtina arkonensis Ehlers & Wright, 1975

Pl. 2-24, figs. 1-10; Table 2-26; Fig. 2-57; Fig. 2-58

1975 *Cyrtina arkonensis* Ehlers & Wright, p. 160-161, pl. 2, figs. 1-10; pl. 3, figs. 1-20.

Types. Holotype UMMP 31283, Arkona Shale Formation, Hamilton Group (Middle Devonian), Crinoid Hill, near Thedford, Ontario.

Description. Shell medium-sized, triangular-hemipyramidal, ventribiconvex; the maximum width along hinge line; hinge line straight; cardinal extremities slightly extended in some valves; surface of shell marked by simple rounded costae (8-10 in number per flank), crossed by fine and weak growth lines; surfaces of costae, fold, and sulcus covered by minute spinules; anterior commissure uniplicate.

Ventral valve moderately convex; ventral sulcus relatively shallow, rounded; a faint median depression present in sulcus in some specimens; beak very small, slightly incurved; interarea wider than high, slightly concave; delthyrium covered with a convex pseudodeltidium, bearing a relatively large oval foramen close to apex; fine, horizontal growth lines present in ventral interarea.

Ventral interior with obvious primary shell and secondary shell; spondylium well-developed, bearing tichorhinum, supported by a long and thin median septum; dental plates long, thin, divergent; hinge teeth sub-rectangular.

Dorsal valve gently convex, subrectangular in outline; dorsal fold narrow and low, a shallow median depression present on fold in most specimens; dorsal interarea linear.

In posterior part of dorsal valve, cardinal process large, bilobed; sockets relatively deep, bounded by prominent inner socket ridges; anteriorly, dorsal median septum relatively obvious, stout (Figure 2-57).

Material. Total 35 complete specimens and 15 incomplete specimens.

Occurrence. Arkona Shale Formation; Arkona-Thedford-Ipperwash area, southwestern Ontario.

Discussion. Cyrtina arkonensis Ehlers & Wright, 1975 differs from *C. angularis* in its shallower sulcus and higher numbers of costae on its exterior shell surface. Although

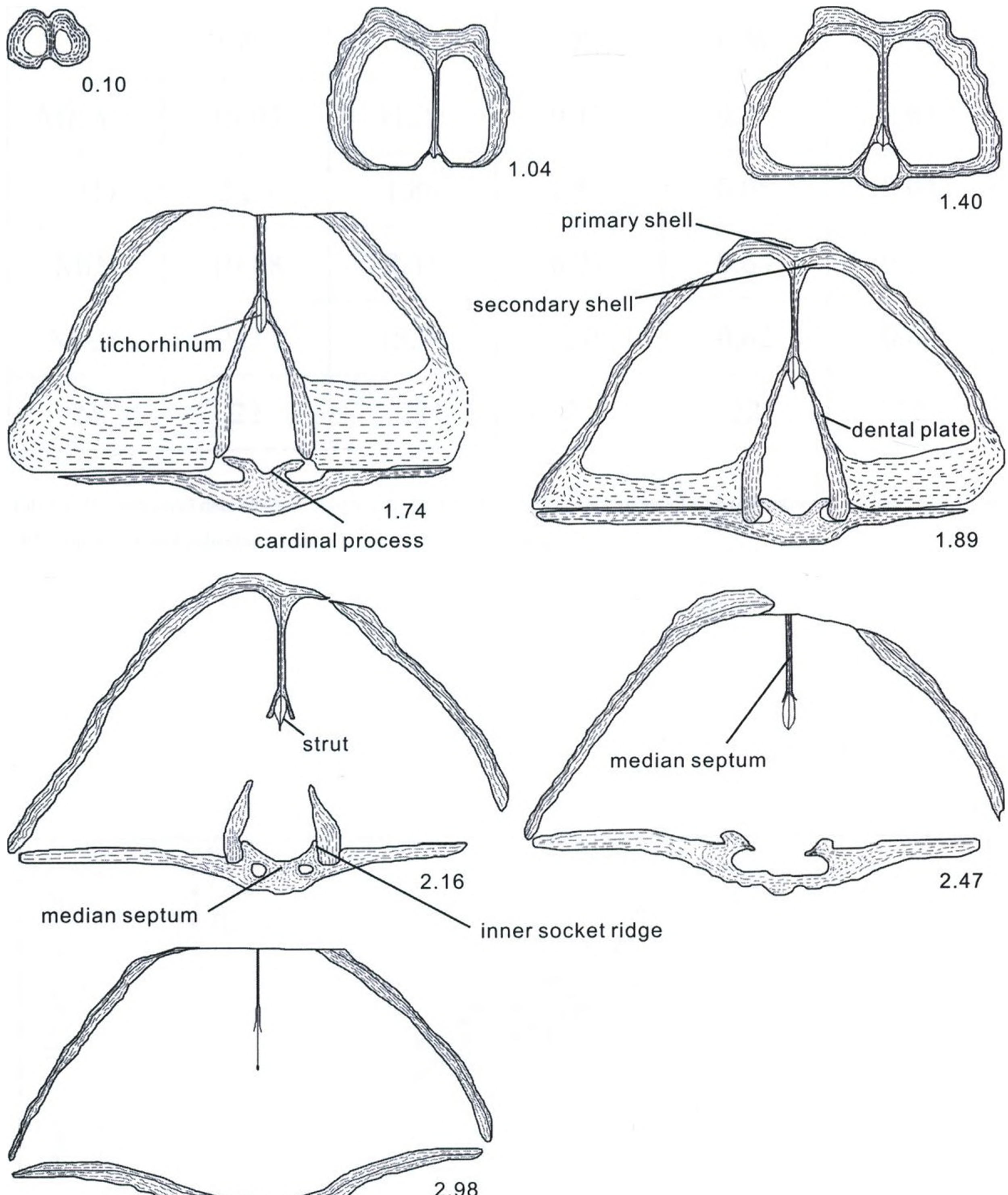


Fig. 2-57. Selected transverse serial sections of *Cyrtina arkonensis* Ehlers & Wright, 1975. W 2871. Arkona Shale. Collecting locality 4. Distances in mm from posterior tip of ventral umbo. X5.0

	W	L	T	L/W	T/W
MEAN	15.05	11.24	9.17	0.75	0.61
STD	2.23	1.88	1.51	0.05	0.04
MIN	10.88	8.31	6.21	0.64	0.53
MAX	19.17	15.70	12.08	0.82	0.68
N	22	22	22	22	22

Table 2-26. Statistical data of shell dimensions (mm) for complete specimens of *Cyrtina arkonensis* Ehlers & Wright, 1975, sample from Collecting locality 2, Arkona Shale Formation.

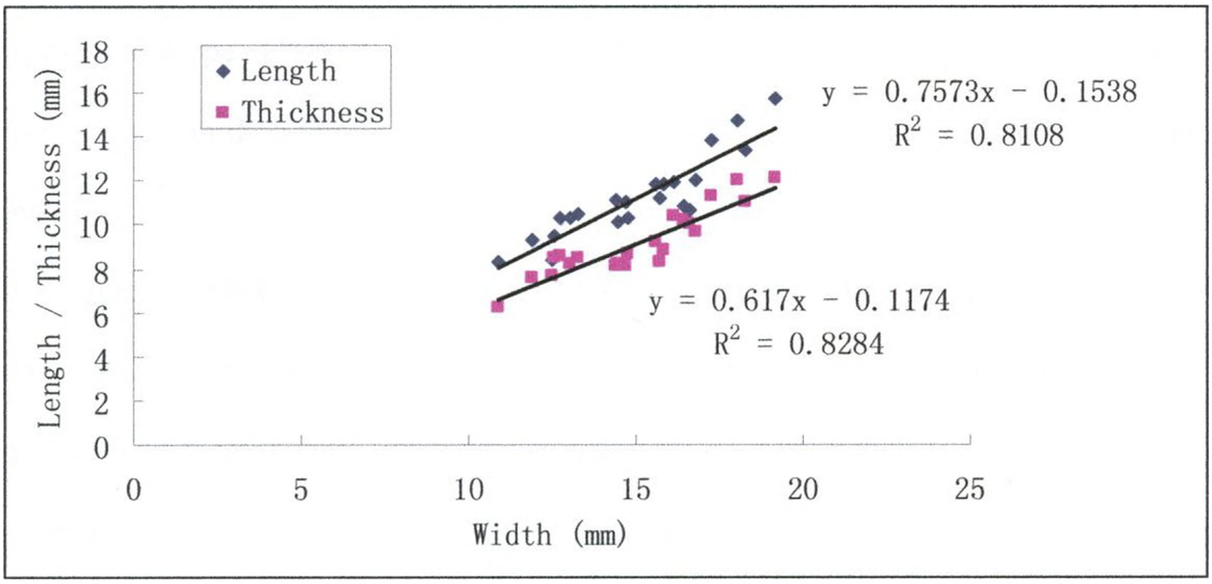


Fig. 2-58. Length-width and thickness-width graphs for complete specimens of *Cyrtina arkonensis* Ehlers & Wright, 1975, sample from Collecting locality 2, Arkona Shale Formation.

they are similar internally, *C. arkonensis* is distinguishable from *C. angularis* by its thinner median septum and dental plates, and its presence of stout median septum in dorsal valve. Although *C. thaeroptera* Keyes & Pitrat, 1978 from the Four Mile Dam Formation and the Norway Point Formation of the Middle Devonian Traverse Group of Michigan (Keyes & Pitrat, 1978, p. 229-230, pl. 2, figs. 11-15; text-figs. 5A, 8, 9) resembles *C. arkonensis* in overall shape, it has a sulcus and a fold of lower amplitude, and higher, more angular costae than *C. arkonensis*.

Cyrtina coultisorum Ehlers & Wright, 1975

Pl. 2-24, figs. 16-20; Table 2-27; Fig. 2-59; Fig. 2-60

1975 *Cyrtina coultisorum* Ehlers & Wright, p. 159-160, pl. 1, figs. 14-21; pl. 2, figs. 26-28.

Types. Holotype UMMP 61523, Coral Unit, Hungry Hollow Member, Widder Formation, Hamilton Group (Middle Devonian), Tile Yard, Thedford, Lambton County, Ontario.

Description. Shell small-sized, triangular-hemipyramidal, ventribiconvex; the maximum width anterior to hinge line; hinge line straight; cardinal extremities not extended; surface of shell marked by simple rounded costae (2-4 in number per flank), crossed by fine and weak growth lines; surfaces of costae, fold, and sulcus covered by minute spinules; anterior commissure uniplicate.

Ventral valve moderately convex; ventral sulcus deep, rounded, median depression absent; beak small, flat to slightly incurved; interarea slightly concave; interarea wider than high in some specimens; delthyrium narrow, partly closed by convex pseudodeltidium, bearing a relatively small oval foramen close to apex; fine, horizontal growth lines present in ventral interarea.

In ventral valve, primary shell and secondary shell obvious; ventral valve with relatively smaller spondylium, bearing thin tichorhinum, supported by a relatively short and thin median septum; dental plates long and thin, divergent; hinge teeth sub-rectangular.

Dorsal valve slightly convex, subrectangular; dorsal fold narrow and relatively high, median depression faint to inconspicuous; dorsal interarea linear.

Dorsal interior with bilobed cardinal process; sockets relatively shallow, bounded by prominent inner socket ridges; dorsal median septum absent (Figure 2-59).

Material. Total 18 complete specimens and 4 incomplete specimens.

Occurrence. Hungry Hollow Member, Widder Formation; Arkona-Thedford-Ipperwash area, southwestern Ontario.

Discussion. Although *Cyrtina coultisorum* Ehlers & Wright, 1975 resembles *C. southworthi* in its small size, it is distinguished from the latter species by its higher and narrower fold, more prominent growth lamellae, and more coarse spinules (Ehlers and Wright, 1975, p. 160).

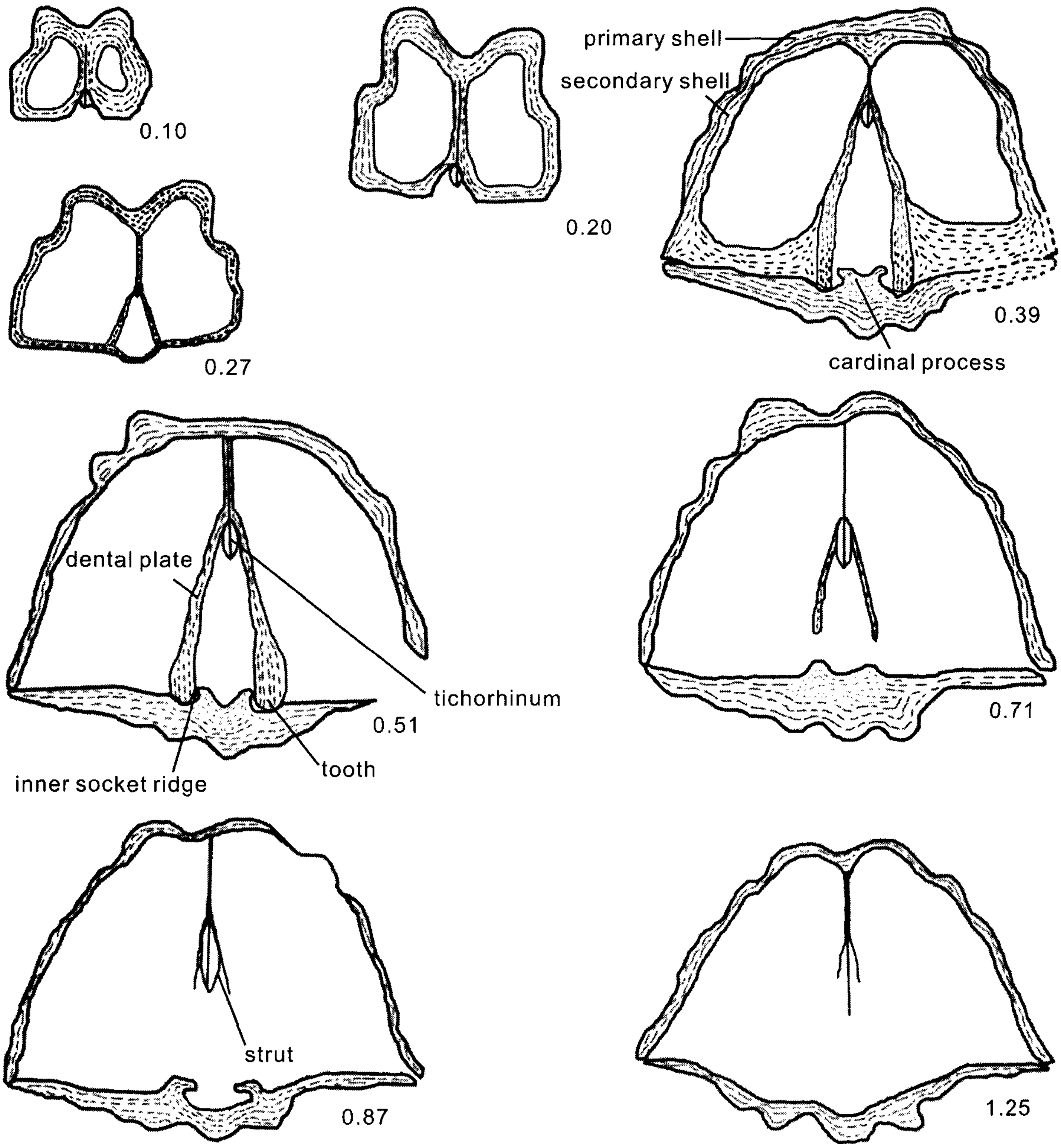


Fig. 2-59. Selected transverse serial sections of *Cyrtina coultisorum* Ehlers & Wright, 1975. W 2870. Coral Unit, Hungry Hollow Member, Widder Formation. Collecting locality 3. Distances in mm from posterior tip of ventral umbo. X10.0

	W	L	T	L/W	T/W
MEAN	5.33	3.95	3.59	0.73	0.68
STD	1.21	1.27	0.88	0.09	0.08
MIN	3.90	2.71	2.39	0.58	0.59
MAX	7.62	6.64	5.25	0.87	0.83
N	13	13	13	13	13

Table 2-27. Statistical data of shell dimensions (mm) for complete specimens of *Cyrtina coultisorum* Ehlers & Wright, 1975, sample from Collecting locality 5, Coral Unit, Hungry Hollow Member, Widder Formation.

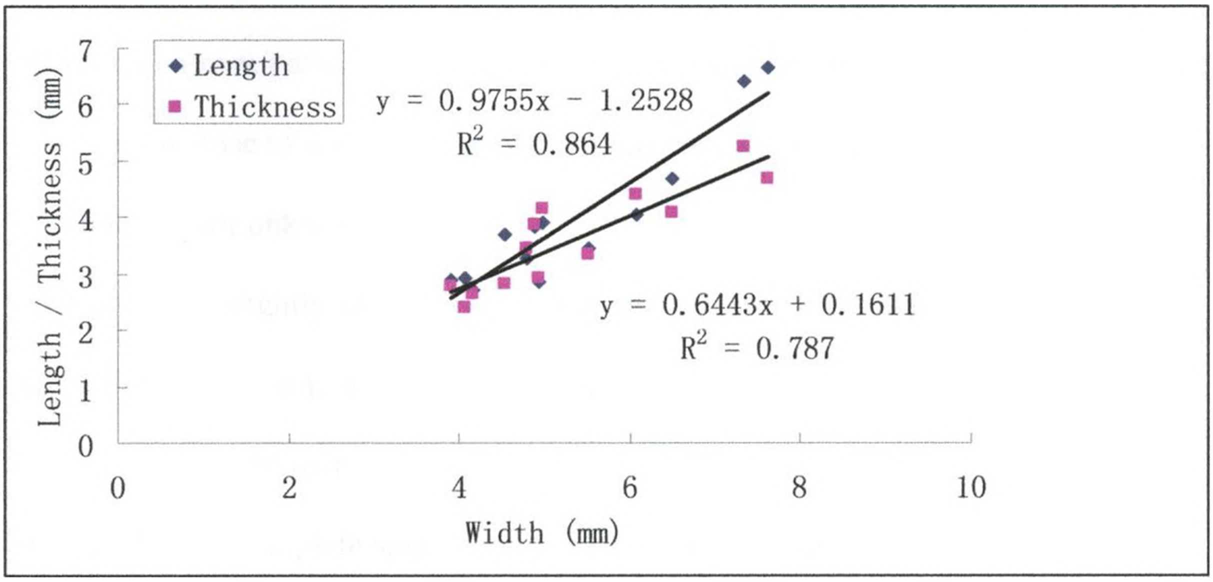


Fig. 2-60. Length-width and thickness-width graphs for complete specimens of *Cyrtina coultisorum* Ehlers & Wright, 1975, sample from Collecting locality 5, Coral Unit, Hungry Hollow Member, Widder Formation.

Cyrtina staufferi Wright & Wright, 1963

Pl. 2-24, figs. 21-25

1963 *Cyrtina staufferi* Wright & Wright, p. 128-129, pl. 2, figs. 1-15.

1972 *Cyrtina staufferi* Wright & Wright; Johnson & Norris, p. 571, pl. 1, figs. 1-4.

Types. Holotype UMMP 46112, Ipperwash Limestone, Middle Devonian Hamilton Group, 2 miles (~ 3.22 km) south of Kettle Point, Shore of Lake Huron, Lambton County, Ontario.

Description. Shell medium-sized, triangular-hemipyramidal, ventribiconvex; the maximum width anterior to hinge line; hinge line straight; cardinal extremities slightly extended in some specimens; surface of shell marked by simple rounded costae (6-8 in number per flank), crossed by fine and weak growth lines; surfaces of costae, fold, and sulcus covered by minute spinules; anterior commissure uniplicate.

Ventral valve moderately convex; ventral sulcus shallow, rounded; a narrow median depression present in sulcus; beak small, incurved; interarea concave, wider than high; delthyrium narrow, partly closed by convex pseudodeltidium, bearing a relatively small oval foramen close to apex; fine, horizontal growth lines present in ventral interarea.

Ventral interior unknown.

Dorsal valve slightly convex, subrectangular; dorsal fold relatively low, bearing a fine median depression; dorsal interarea linear.

Dorsal interior unkown.

Material. Total 3 complete specimens and 12 incomplete specimens.

Occurrence. Widder Formation; Ipperwash Limestone; Arkona-Thedford-Ipperwash area, southwestern Ontario.

Discussion. *Cyrtina arkonensis*, *C. angularis* and *C. staufferi* are larger in size than *C. coultisorum* and *C. southworthi*. *C. staufferi* resembles *C. angularis* more closely than other species, but is still distinguished by its smaller size, more delicate costae, and shallower sulcus relative to *C. angularis*. *C. quadrata* Keyes & Pitrat, 1978 from the Middle Devonian Traverse Group of Michigan (Keyes & Pitrat, 1978, p. 230-231, pl. 2, figs. 6-10; text-figs. 5D, 6, 7) is similar in overall appearance to *C. staufferi,* but differs in having angular costae, and also having a higher ventral interarea and less curved beak than the latter species.

Order TEREBRATULIDA Waagen, 1883

Suborder TEREBRATULIDINA Waagen, 1883

Superfamily CRYPTONELLOIDEA Thomson, 1926

Family CRANAENIDAE Cloud, 1942

Subfamily CRANAENINAE Cloud, 1942

Genus *Cranaena* Hall & Clarke, 1894b

Type species: *Terebratula romingeri* Hall, 1863b, shale beds, Middle Devonian Hamilton Group, Thunder Bay Island, Michigan.

Cranaena romingeri (Hall, 1863)

Pl. 2-15, figs. 1-10; Table 2-28; Fig. 2-61; Fig. 2-62

1863b *Terebratula romingeri* Hall, p. 48, figs. 22-23.

1867 *Terebratula romingeri*; Hall, p. 389, pl. 60, figs. 17-25, 66-67.

1889 *Terebratula romingeri*; Nettelroth, p. 155, pl. 16, figs. 20-22.

1894b *Cranaena romingeri*; Hall & Clarke, p. 297, fig. 215; pl. 80, figs. 13-19.

1898 *Cranaena romingeri*; Whiteaves, p. 390.

1902 *Cranaena romingeri*; Shimer & Grabau, p. 182.

1938 *Cranaena romingeri*; Cooper & Cloud, p. 449, pl. 54, figs. 9-11, 17-18.

1958 *Cranaena romingeri*; Stumm & Wright, p. 106.

1961 *Cranaena romingeri*; Fagerstrom, p. 35, pl. 11, figs. 20-24.

2007 *Cranaena romingeri*; Modzalevskaya, p. 878.

Types. The original specimens figured by Hall (1863b) were from shale beds of the Middle Devonian Hamilton Group, Thunder Bay Island, Michigan, but the author's original description did not include a holotype designation. Original types cannot be traced from previous references.

Description. Shell small to medium, smooth, elongate, biconvex; surface of shell covered by irregular and fine growth lines; maximium width located at about 3/5 of the shell length from the ventral umbo; anterior commissure rectimarginate to slightly uniplicate.

Ventral valve strongly convex in lateral profile with maximum convexity located at umbonal area; oval foramen prominent, permesothyrid; ventral sulcus shallow to ill-defined.

Ventral interior with pedicle collar; small teeth projecting obliquely towards one another, supported posteriorly by slender convergent dental plates; ventral median septum absent.

Dorsal valve moderately convex in lateral profile with highest point immediately posterior to mid-length; dorsal fold inconspicuous.

Dorsal interior with perforate hinge plate; dorsal median septum absent; details of loop not preserved in the sectioned specimens (Figure 2-61).

Material. Total 182 complete specimens.

Occurrence. Hungry Hollow Member, Widder Formation; Arkona-Thedford-Ipperwash area, southwestern Ontario.

Discussion. *Cranaena cooperi* Cloud, 1941 from the Middle Devonian Milwaukee Formation of southeastern Wisconsin (Griesemer, 1965, p. 290, 292, pl. 6, figs. 14-17) differs from *Cranaena romingeri* (Hall, 1863) (Table 2-28) in its larger size (average width: 14.2 mm; average length: 16.4 mm; average thickness: 7.9 mm), subelliptical to subcircular outline, and smaller length/width and thickness/width ratios (1.15 and 0.56 respectively). *C.* cf.*C. lincklaeni* (Hall, 1860) (Griesemer, 1965, p. 292, pl. 6, figs. 18-19) is similar in elongate outline to *C. romingeri*; however, the former species is larger in size (average width: 13.1 mm; average length: 17.1 mm; average thickness: 8.1 mm) and has a smaller thickness/width ratio (0.62). Although *C. briceae* Li & Jones, 2003 from the late Early Devonian to Middle Devonian Bird Fiord Formation, Arctic Canada (Li & Jones, 2003, p. 263, figs. 19.1-19.16, 20) is similar to *C. romingeri* in its elongate outline, it differs from the latter species in having a mesothyridid foramen.

Cranaena harmonia (Hall, 1867)

Pl. 2-15, figs. 11-15; Table 2-29; Fig. 2-63; Fig. 2-64

1867 *Terebratula harmonia* Hall, p. 388, pl. 60, figs. 11-16.

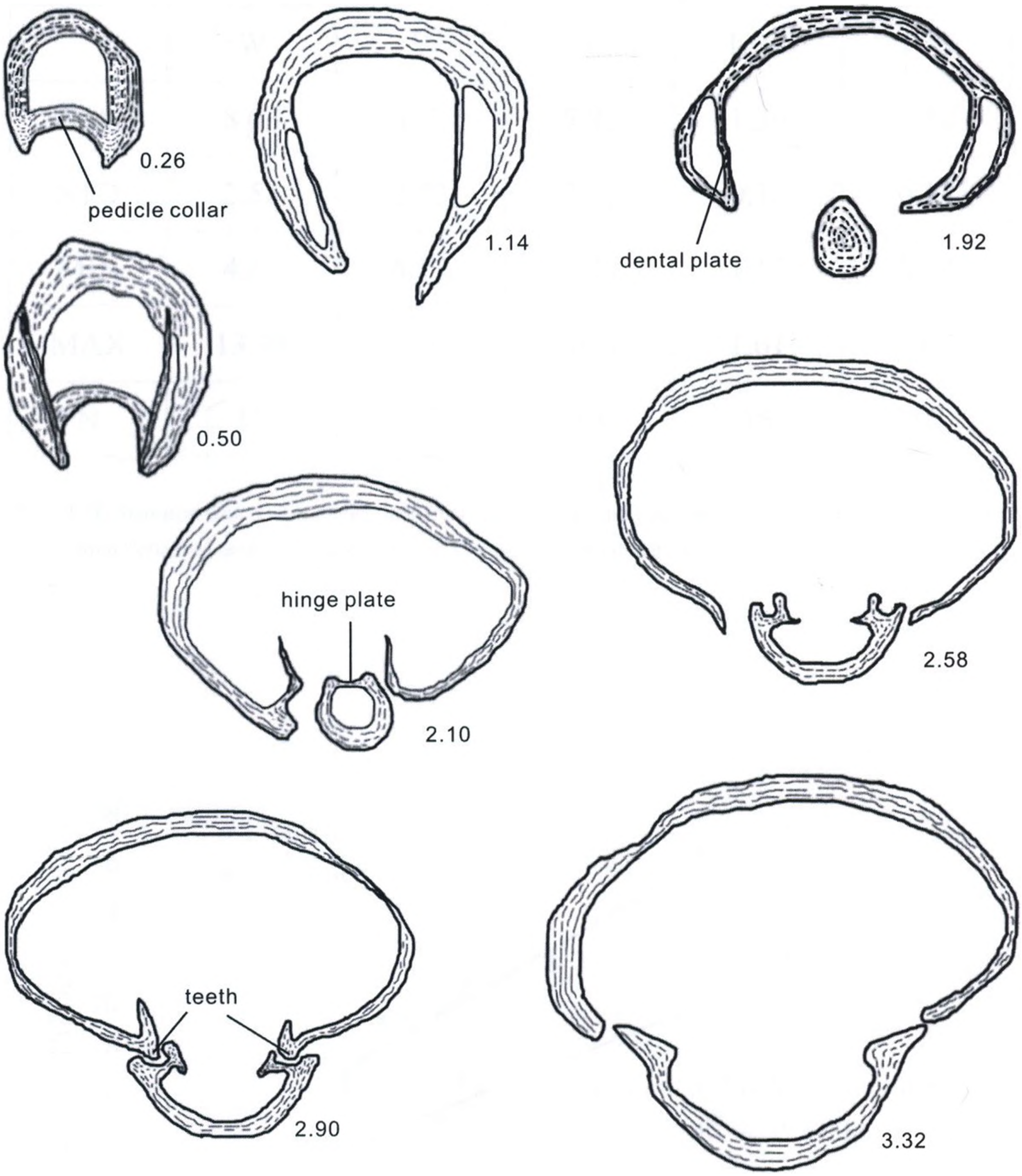


Fig. 2-61. Selected transverse serial sections of *Cranaena romingeri* (Hall, 1863). W 2863. Coral Unit, Hungry Hollow Member, Widder Formation. Collecting locality 5. Distances in mm from posterior tip of ventral umbo. X10.0

	W	L	T	L/W	T/W
MEAN	8.03	10.29	5.92	1.30	0.74
STD	2.51	2.73	2.02	0.12	0.13
MIN	4.82	6.17	2.96	1.15	0.57
MAX	13.28	16.34	10.34	1.61	1.07
N	15	15	15	15	15

Table 2-28. Statistical data of shell dimensions (mm) for complete specimens of *Cranaena romingeri* (Hall, 1863), sample from Collecting locality 5, Hungry Hollow Member, Widder Formation.

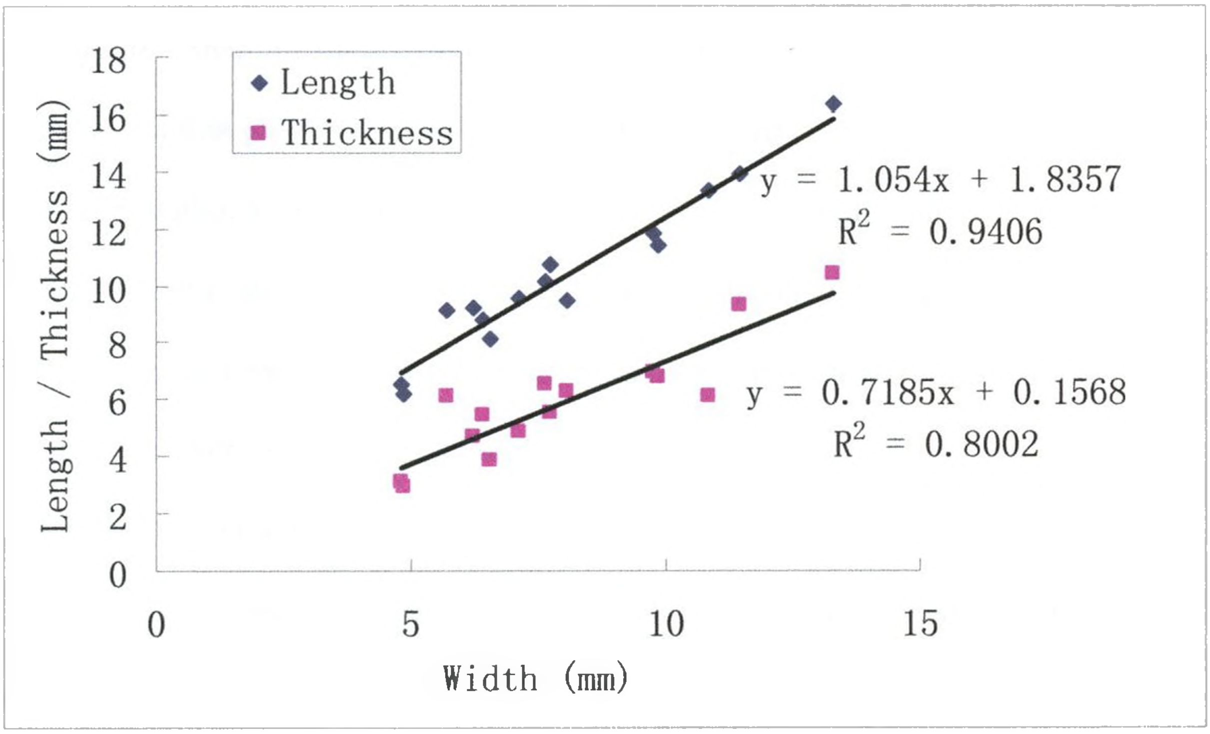


Fig. 2-62. Length-width and thickness-width graphs for complete specimens of *Cranaena romingeri* (Hall, 1863), sample from Collecting locality 5, Hungry Hollow Member, Widder Formation.

1889 *Terebratula harmonia*; Nettelroth, p. 154, pl. 17, figs. 1-4.

1894b *Eunella harmonia*; Hall & Clarke, p. 290, pl. 80, figs. 33-35.

1898 *Eunella harmonia*; Whiteaves, p. 389.

1902 *Eunella harmonia*; Shimer & Grabau, p. 182.

1915 *Eunella harmonia*; Stauffer, p. 160.

1958 *Cranaena harmonia*; Stumm & Wright, p. 106.

1981 *Cranaena harmonia*; Oliver, p. 876.

Types. Hall's (1867) original description was based on specimens from Devonian limestone beds exposed at the Falls of the Ohio River, near Louisville, Kentucky, U.S.A., and from the so-called Corniferous Limestone (probably the Onondaga Limestone) of Canada West. There was no holotype designation in his original description. Original types can not be traced from previous references.

Description. Shell medium-sized, elongate, biconvex; surface of shell covered by irregular and fine growth lines; maximium width located at about 1/2 of the length from the ventral umbo; anterior commissure rectimarginate to slightly uniplicate.

Ventral valve strongly convex; oval foramen prominent, permesothyrid; ventral sulcus ill-defined; ventral interarea in adult shells relatively high (2.3-2.5 mm).

Ventral interior with pedicle collar; dental plates thin, long.

Dorsal valve moderately convex; dorsal fold inconspicuous.

Dorsal interior with perforate hinge plate; dorsal median septum absent; details of loop not preserved in the sectioned specimens (Figure 2-63).

Material. Total 45 complete specimens and 16 incomplete specimens.

Occurrence. Hungry Hollow Member, Widder Formation; Arkona-Thedford-Ipperwash

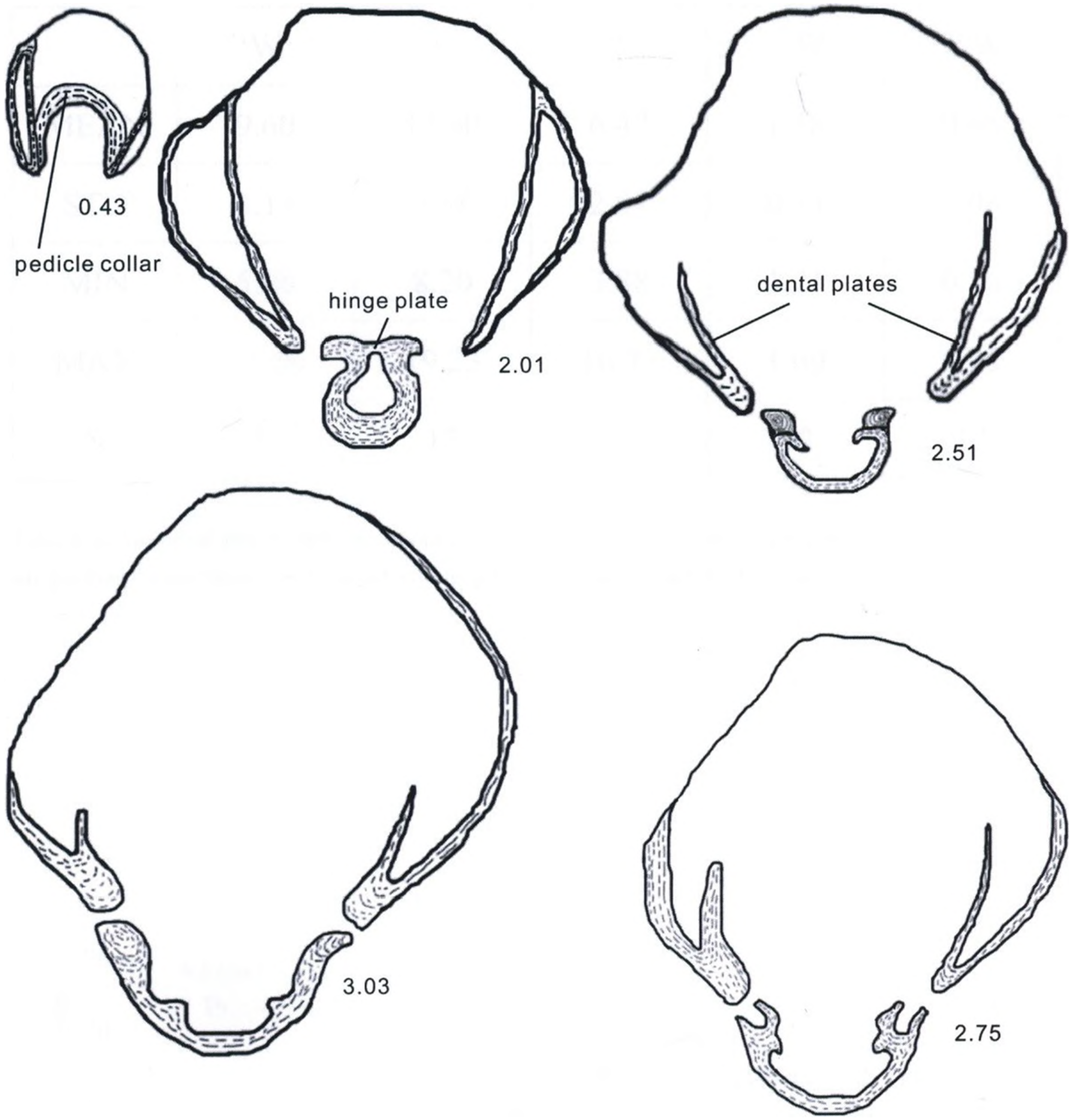


Fig. 2-63. Selected transverse serial sections of *Cranaena harmonia* (Hall, 1867). W 2865. Coral Unit,Hungry Hollow Member, Widder Formation. Collecting locality 3. Distances in mm from posterior tip of ventral umbo. X10.0

	W	L	T	L/W	T/W
MEAN	9.60	13.00	6.47	1.38	0.68
STD	3.15	3.58	2.07	0.14	0.08
MIN	5.96	8.20	3.88	1.21	0.56
MAX	15.66	19.23	10.32	1.60	0.85
N	12	12	12	12	12

Table 2-29. Statistical data of shell dimensions (mm) for complete specimens of *Cranaena harmonia* (Hall, 1867), sample from Collecting locality 5, Coral Unit, Hungry Hollow Member, Widder Formation.

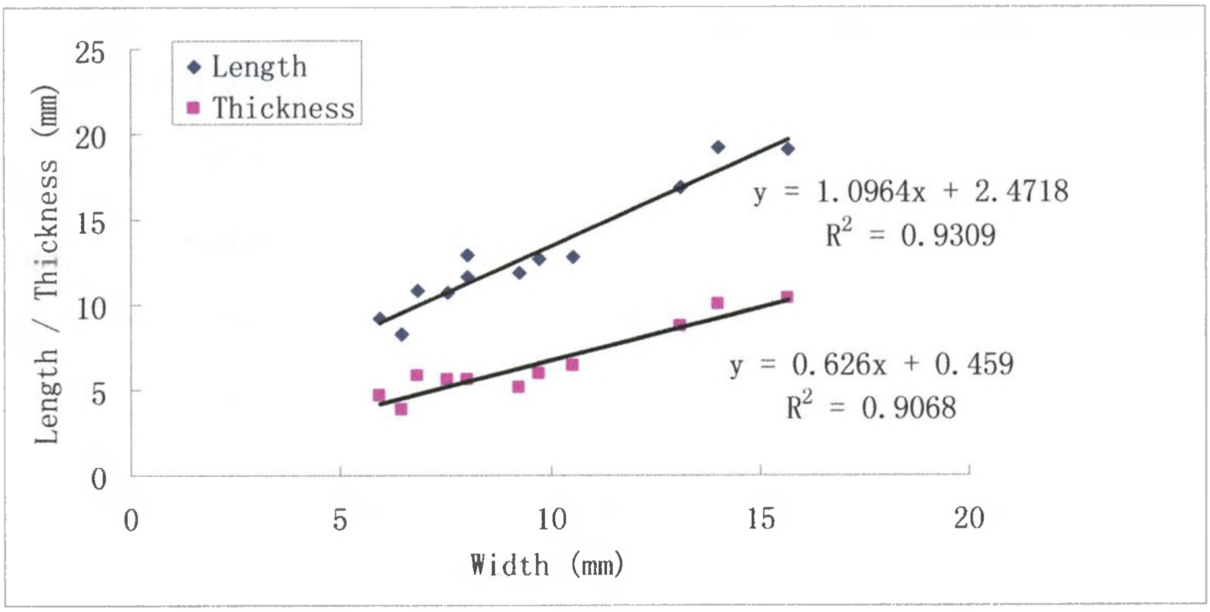


Fig. 2-64. Length-width and thickness-width graphs for complete specimens of *Cranaena harmonia* (Hall, 1867), sample from Collecting locality 5, Coral Unit, Hungry Hollow Member, Widder Formation.

area, southwestern Ontario.

Discussion. Cranaena thomasi Stainbrook, 1941 from the Middle Devonian Milwaukee Formation of southeastern Wisconsin (Griesemer, 1965, p. 293, pl. 6, figs. 22-25) is distinguished from *C. harmonia* (Hall, 1867) in having a subovate to ovate outline (smaller length/width ratio: 1.17), being larger in size (average width: 18.7 mm; average length: 21.8 mm; average thickness: 9.6 mm), and in having a smaller thickness/width ratio (0.51) than the latter. *C. boucoti* Fagerstrom, 1971 from the Middle Devonian (late Eifelian) Detroit River Group of southwestern Ontario and adjacent areas of Michigan and Ohio (Fagerstrom, 1971, p. 55-56, pl. IV, figs. 23-26) differs from *C. harmonia* (Table 2-29) in its subpentagonal outline, smaller size, smaller length/width ratio (1.25) and conjunct deltidial plates. Also, longitudinally striate muscle tracks occur on the interior surface of ventral valve of *C. boucoti*.

Family CRYPTONELLIDAE Thomson, 1926

Subfamily CRYPTONELLINAE Thomson, 1926

Genus *Cryptonella* Hall, 1861

Type species: *Terebratula rectirostra* Hall, 1860b, shale beds, Hamilton Group (Middle Devonian), western New York.

Cryptonella attenuata (Whiteaves, 1898)

Pl. 2-11, figs. 16-25; Table 2-30

1898 *Eunella attenuata* Whiteaves, p. 389-390, fig. 4.

1902 *Eunella attenuata*; Shimer & Grabau, p. 182.

1944 *Cryptonella attenuata*; Shimer & Shrock, p. 364, pl. 142, fig. 22.

1958 *Cryptonella attenuata*; Stumm & Wright, p. 106.

Types. Syntypes GSC 3788, a-g, exact locality and horizon unknown, Hamilton Group (Middle Devonian), Thedford, Ontario, Canada.

Description. Shell small-sized, elongate, subtriangular; valves subequally convex, smooth; anterior commissure rectimarginate.

Ventral valve slightly convex, foramen small, submesothyrid; sulcus ill-defined.

Ventral interior features not preserved through the transverse serial sections of the studied specimens due to the recrystallization.

Dorsal valve slightly convex; fold inconspicuous.

Dorsal interior structures not preserved through the transverse serial sections of the studied specimens due to the recrystallization.

Material. Total 45 complete specimens and 23 incomplete specimens.

Occurrence. Coral Unit, Hungry Hollow Member, Widder Formation; Arkona-Thedford-Ipperwash area, southwestern Ontario.

Discussion. Cryptonella rectirostra (Hall, 1860) from the Middle Devonian Hamilton Group of western New York (Hall, 1867, p. 394, pl. 61, figs. 1-8) is distinguished from *C. attenuata* (Whiteaves, 1898) by its larger size (12.7 ~ 38.1 mm in length), different outline (elongate, ovate, subovate or elliptical) versus elongate subtriangular outline in *C. attenuata*, and obvious concentric growth lines. *C. lens* (Hall, 1860) from the Middle Devonian Formosa Reef Limestone of southwestern Ontario (Fagerstrom, 1961, p. 35, pl. 11, figs. 25-29) differs from *C. attenuata* in its subovate outline and greater convexity of its ventral valve.

	W	L	T	L/W	T/W
MEAN	5.45	8.63	2.56	1.59	0.47
STD	0.81	1.17	0.51	0.15	0.09
MIN	3.78	6.61	1.74	1.35	0.32
MAX	6.97	11.49	3.85	1.93	0.79
N	22	22	22	22	22

Table 2-30. Statistical data of shell dimensions (mm) for complete specimens of *Cryptonella attenuata* (Whiteaves, 1898), sample from Collecting locality 5, Coral Unit, Hungry Hollow Member, Widder Formation.

2.3 Revision of Brachiopod Stratigraphic Ranges

Shimer and Grabau (1902) and Stauffer (1915) studied the Hamilton Group brachiopod stratigraphic ranges in the study area and compiled species lists for the various stratigraphic units recognized in the stratigraphic framework of those times. Somewhat later, Wright and Wright (1961, 1963) examined the brachiopod stratigraphic ranges of the Widder Foramtion and the Ipperwash Limestone in the existing stratigraphic framework, and Stumm and Wright (1958) compiled the faunal lists for the formations within the Hamilton Group.

As it mentioned at the beginning of this chapter, much of the previous work on Hamilton Group fauna was accomplished significantly prior to advent of modern approaches to the study of brachiopods now considered standard for taxonomic investigations of brachiopod taxa. For example, virtually ignored in most of these studies were internal characteristics of brachiopod shells that have since proved valuable in classification. The re-examination of brachiopod taxa in the present study has led to substantial revision of the systematics of brachiopods from the Hamilton Group strata of southwestern Ontario, involving, most notably the consolidation of a number of taxa previously recognized as representing separate forms and the updating of the names of various species and genera. For example, *Elytha fimbriata* (Conrad), included in the faunal list compiled by Stumm & Wright (1958), proved to be outdated and is now reassigned to the genus *Elita*.

Thus, based on the brachiopod specimens collected in the field by the author (their stratigraphic occurrences duly recorded) as well as those made available from the collections of paleontological institutions in both Canada and the U.S.A., the revised taxonomy of Hamilton Group brachiopods now permits the construction of revised brachiopod stratigraphic ranges in the studied interval. Details of the revised framework are provided in Figure 2-65.

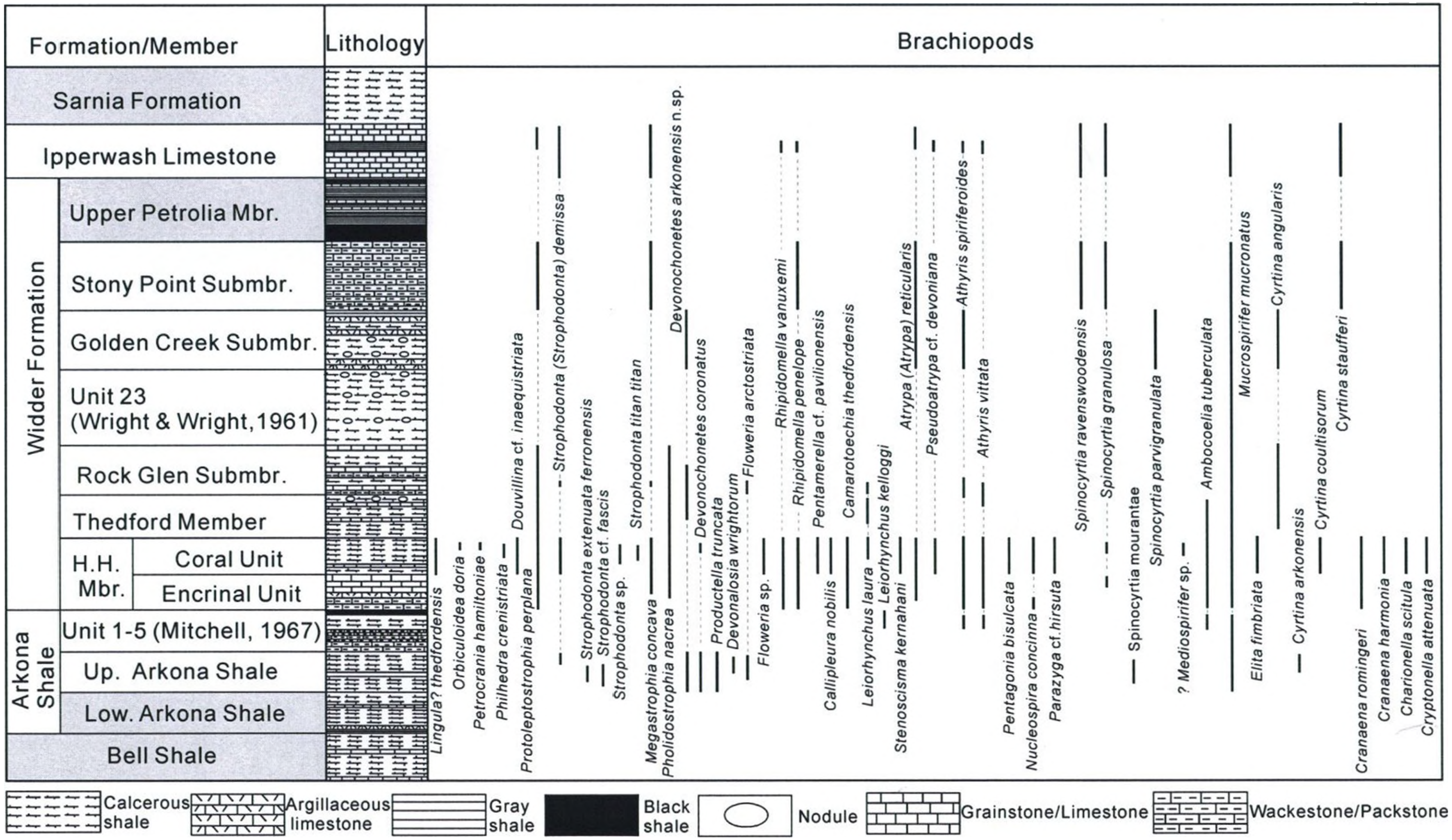


Fig. 2-65. Stratigraphic ranges of brachiopod species in the exposed strata of the Hamilton Group of southwestern Ontario. The strata covered by gray shadow are in the subsurface.

Plate 2-1

Figs. 1-5 *Lingula*? *thedfordensis* Whiteaves, 1889

1-5. dorsal (1), ventral (2), lateral (3), posterior (4), and anterior (5) views of an adult shell; ×5; Coral Unit, Hungry Hollow Member, Widder Formation, Collecting locality 1; W 2874.

Fig. 6 *Orbiculoidea doria* (Hall, 1863)

6. the exterior of a dorsal valve; ×2.5; Coral Unit, Hungry Hollow Member, Widder Formation; Hungry Hollow, Ontario; UMMP 74035.

Fig. 7 *Petrocrania hamiltoniae* (Hall, 1860)

7. the exterior of a ventral valve; ×2; Coral Unit, Hungry Hollow Member, Widder Formation, Collecting locality 1; W 2920.

Fig. 8 *Philhedra crenistriata* (Hall, 1860)

8. the exterior of a dorsal valve; ×3; Coral Unit, Hungry Hollow Member, Widder Formation, Collecting locality 1; W 2921.

Pl. 2-1

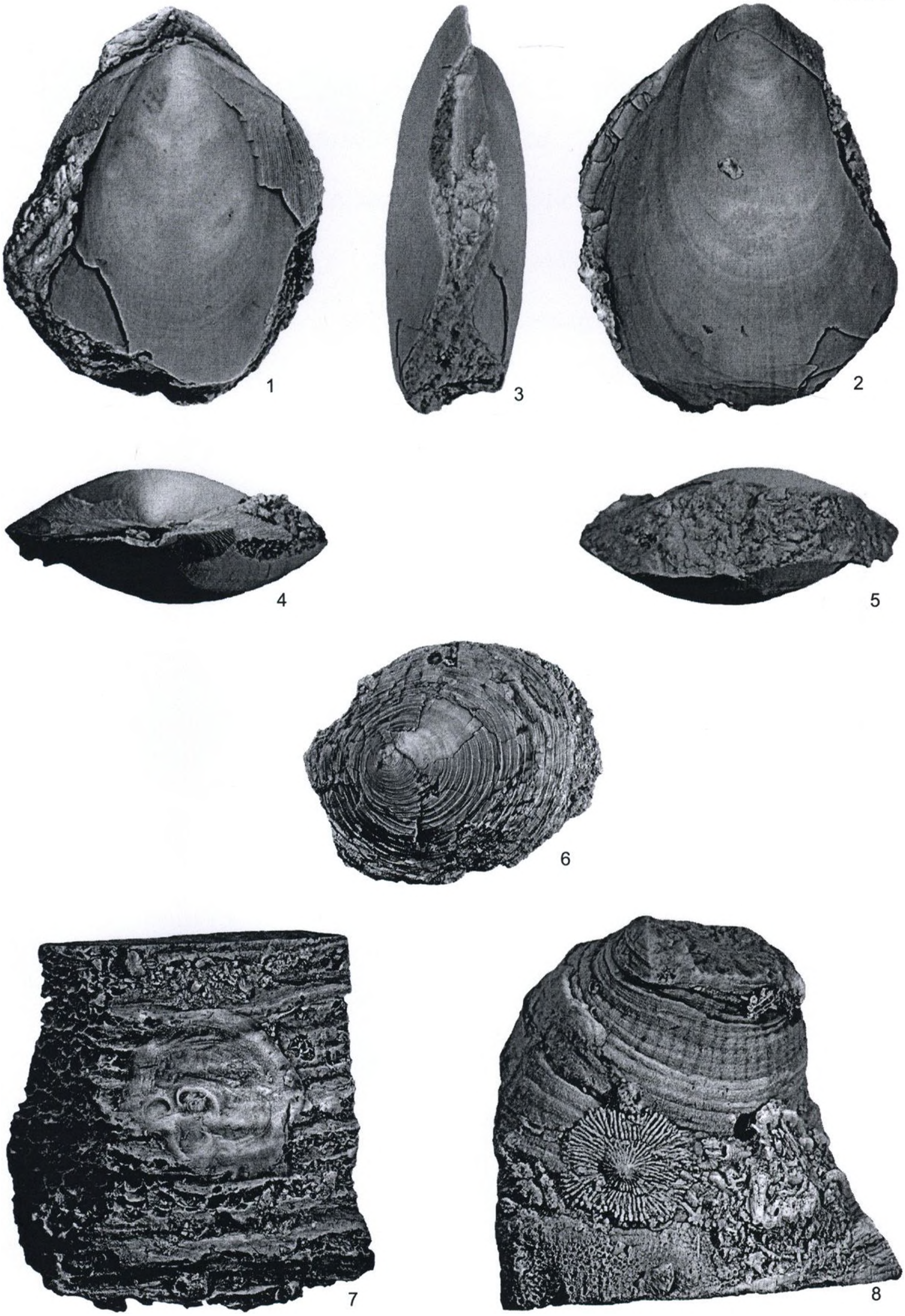


Plate 2-2

Figs. 1-5 *Devonalosia wrightorum* Muir-Wood & Cooper, 1960

1-5. dorsal (1), ventral (2), lateral (3), posterior (4), and anterior (5) views of an adult shell with a concavo-convex profile and thick spines on the surface; ×2; Arkona Shale; Hungry Hollow; UMMP 74032.

Figs. 6-10 *Douvillina* cf. *inaequistriata* (Conrad, 1842)

6-10. dorsal (6), ventral (7), lateral (8), posterior (9), and anterior (10) views of an adult shell with a concavo-convex profile and costellae arranged in groups of fine ones separated by distant stronger ones; ×2; Coral Unit, Hungry Hollow Member, Widder Formation; Hungry Hollow; UMMP 74033.

Figs. 11-15 *Elita fimbriata* (Conrad, 1842)

11-15. dorsal (11), ventral (12), lateral (13), posterior (14), and anterior (15) views of an adult shell; ×2; Coral Unit, Hungry Hollow Member, Widder Formation; Hungry Hollow; UMMP 74029.

Figs. 16-20 *Leiorhynchus laura* (Billings, 1860)

16-20. dorsal (16), ventral (17), lateral (18), posterior (19), and anterior (20) views of an adult shell with an elongated shape in majority of specimens; ×2; Widder Formation; Thedford, Ontario; UMMP 35801A.

Pl. 2-2

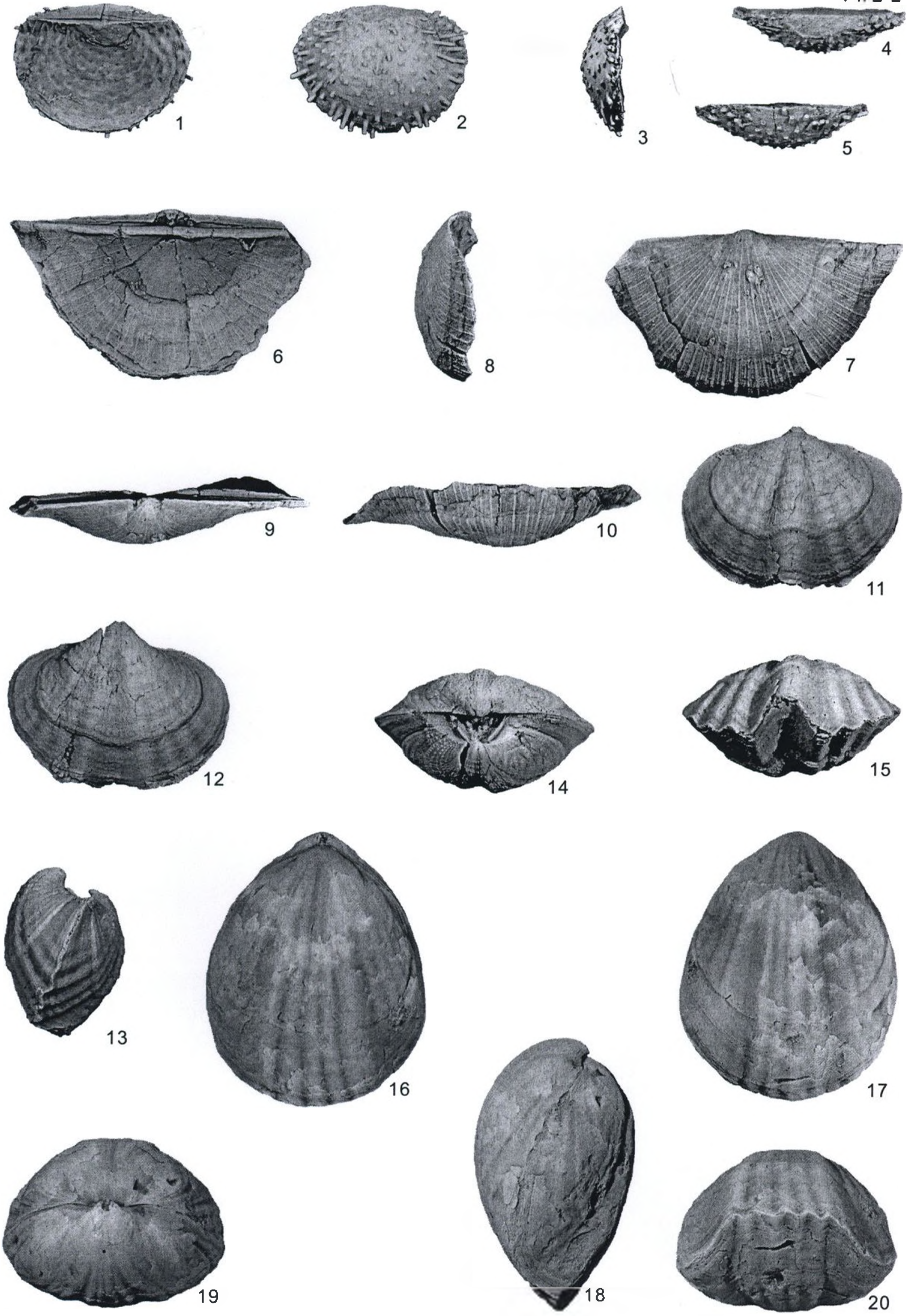


Plate 2-3

Figs. 1-5 *Megastrophia concava* (Hall, 1857)

1-5. dorsal (1), ventral (2), lateral (3), posterior (4), and anterior (5) views of an adult shell; ×1.2; Stony Point Submember, Petrolia Member, Widder Formation, Collecting locality 8; W 2914.

Figs. 6-11 *Protoleptostrophia perplana* (Conrad, 1842)

6-10. dorsal (6), ventral (7), lateral (8), posterior (9), and anterior (10) views of an adult shell; ×1.8; Coral Unit, Hungry Hollow Member, Widder Formation, 2 miles (~ 3.22 km) east and 3/4 mile (~1.21 km) north of Arkona, Ontario; UMMP 74041.

11. the interior of a ventral valve, showing the form of the muscular impression; × 2; Coral Unit, Hungry Hollow Member, Widder Formation, Collecting locality 5; W 2919.

Pl. 2-3

Plate 2-4

Figs. 1-16 *Strophodonta* (*Strophodonta*) *demissa* (Conrad, 1842)

1-5. dorsal (1), ventral (2), lateral (3), posterior (4), and anterior (5) views of a juvenile shell with less costellae on the surface; ×2; Coral Unit, Hungry Hollow Member, Widder Formation, Collecting locality 1; W 2911.

6-10. dorsal (6), ventral (7), lateral (8), posterior (9), and anterior (10) views of an adult shell with more plications on the surface; ×1.2; Coral Unit, Hungry Hollow Member, Widder Formation, Collecting locality 3; W 2912.

11-15. dorsal (11), ventral (12), lateral (13), posterior (14), and anterior (15) views of an adult shell with a lower degree of convexity; ×1.5; Coral Unit, Hungry Hollow Member, Widder Formation, Collecting locality 1; W 2908.

16. the interior of a dorsal shell, showing the strong cardinal process, denticulate hinge line, and the form of the muscular impression; ×1.5; Coral Unit, Hungry Hollow Member, Widder Formation, Collecting locality 1; W 2909.

Pl. 2-4

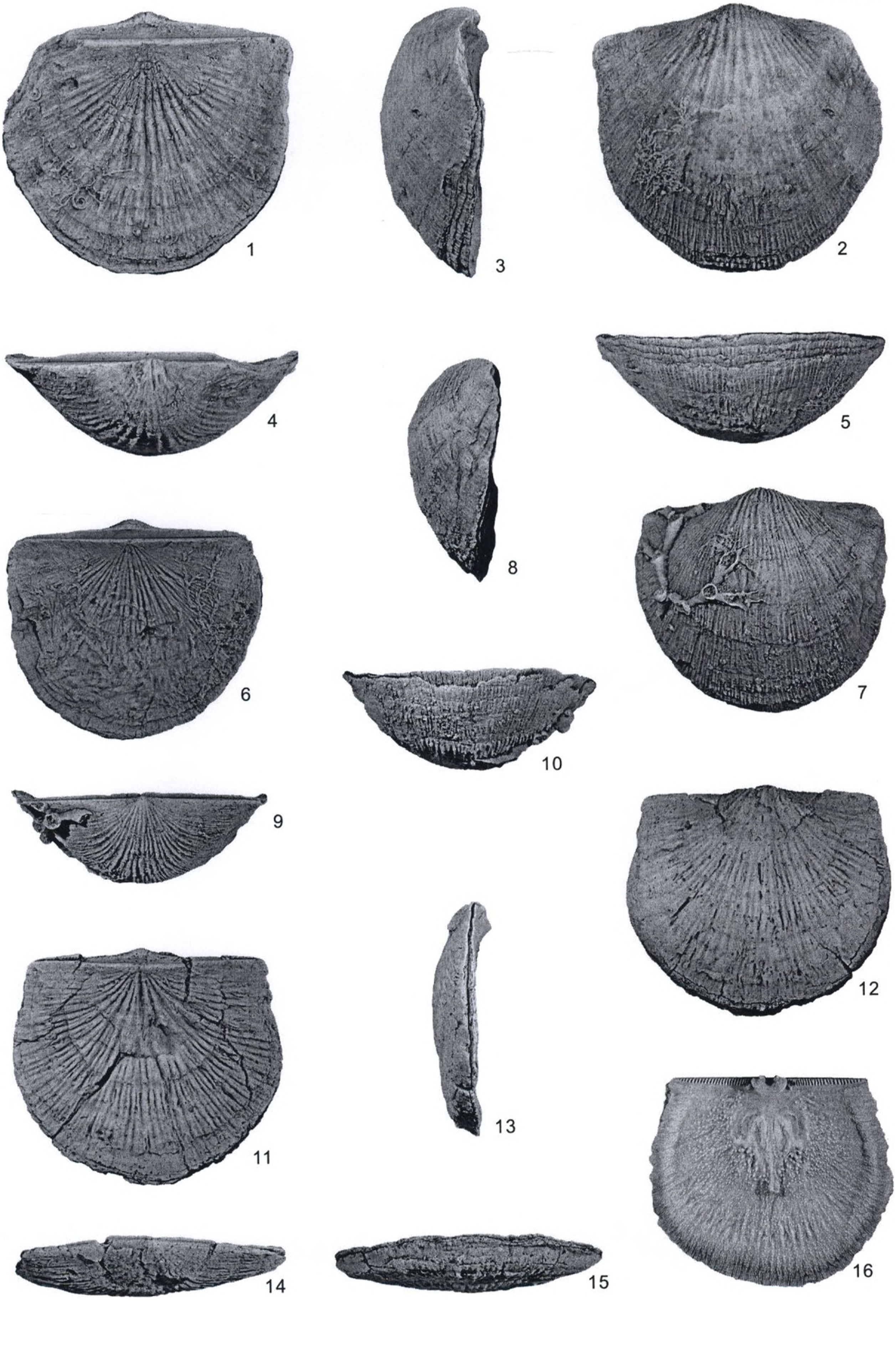


Plate 2-5

Figs. 1-5 *Strophodonta extenuata ferronensis* Imbrie, 1955

1-5. dorsal (1), ventral (2), lateral (3), posterior (4), and anterior (5) views of an adult shell with transversely subelliptical outline; ×1.5; Arkona Shale, Collecting locality 6; W 2907.

Figs. 6-10 *Strophodonta* cf. *fascis* Imbrie, 1959

6-10. dorsal (6), ventral (7), lateral (8), posterior (9), and anterior (10) views of an adult shell with subquadrate outline; ×1.8; Arkona Shale, Collecting locality 6; W 2910.

Pl. 2-5

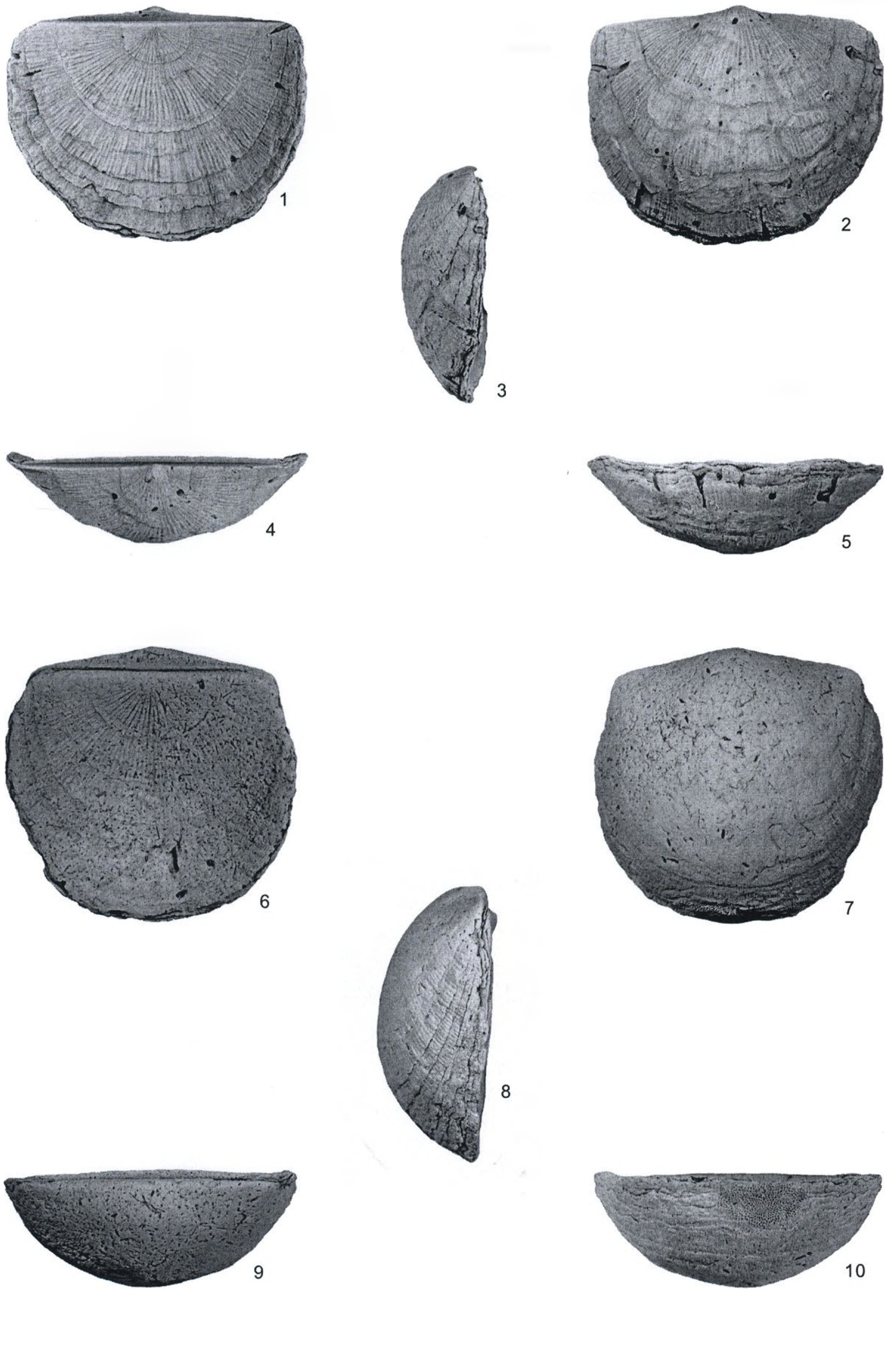


Plate 2-6

Figs. 1-5 *Strophodonta* cf. *fascis* Imbrie, 1959

1-5. dorsal (1), ventral (2), lateral (3), posterior (4), and anterior (5) views of an adult shell with subquadrate outline and extended cardinal extremities; ×1.5; Arkona Shale, Lot 8, Arkona, Ontario; UMMP 74040.

Figs. 6-7 *Strophodonta extenuata ferronensis* Imbrie, 1955

6. The interior of a dorsal valve, showing the form of the muscular impression; ×1.5; Arkona Shale, Lot 8, Arkona, Ontario; UMMP 74047.

7. The interior of a ventral valve, showing the form of the muscular impression; ×1.8; Arkona Shale, Arkona-Thedford range, southwestern Ontario; UMMP 74046.

Figs. 8-9 *Strophodonta* sp.

8. The interior of a dorsal valve, showing the cardinal process, denticulate hinge line, and the form of the muscular impression; ×2.4; southwestern Ontario; UMMP 74027.

9. The interior of a ventral valve, showing the form of the muscular impression; ×3; southwestern Ontario; UMMP 74028.

Figs. 10-14 *Devonochonetes arkonensis* n. sp.

10-14. dorsal (10), ventral (11), lateral (12), posterior (13), and anterior (14) views of a paratype shell; ×4.5; Arkona Shale, Collecting locality 1; W 2915.

Pl. 2-6

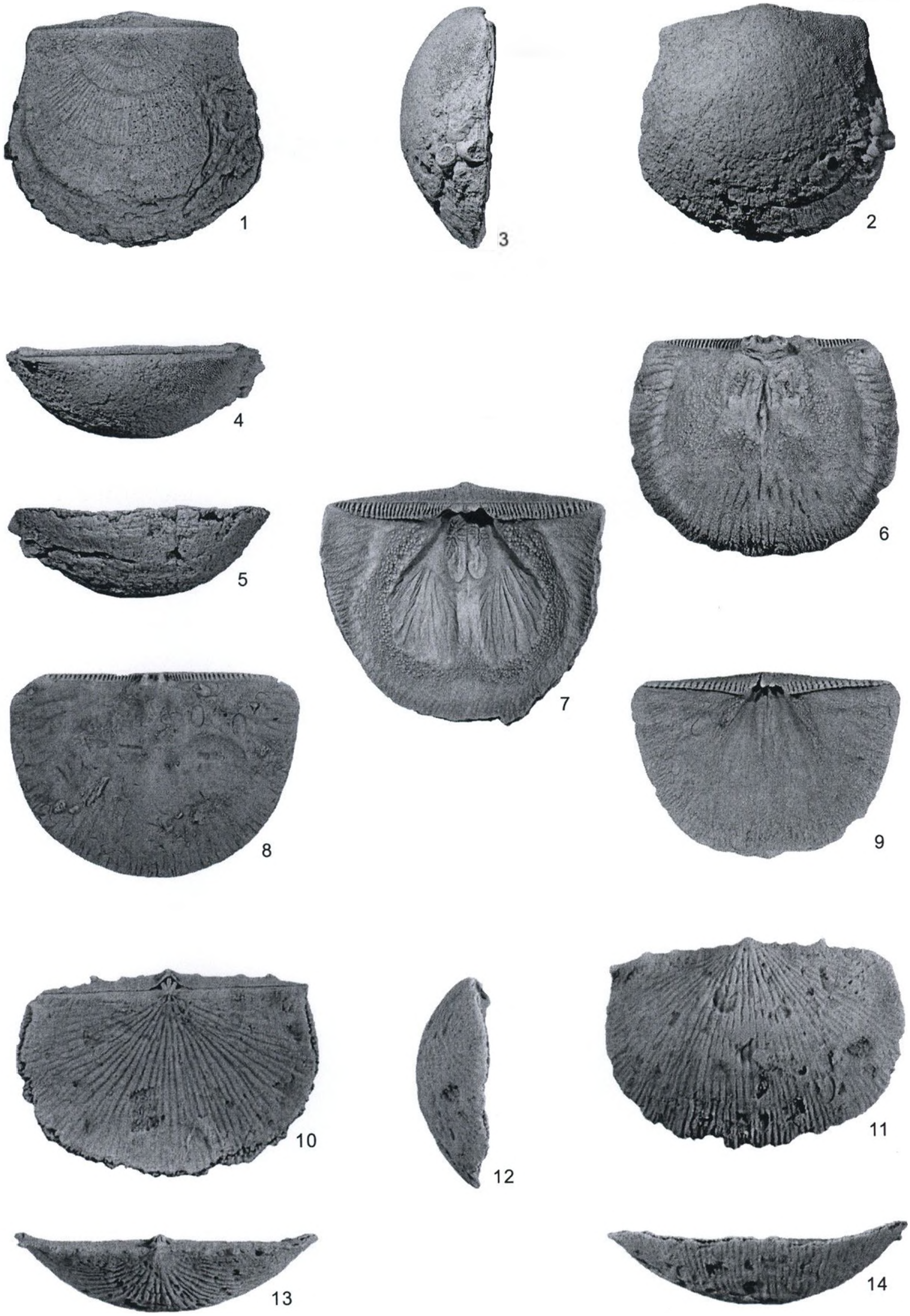


Plate 2-7

Figs. 1-5 *Devonochonetes coronatus* (Conrad, 1842)

1-5. dorsal (1), ventral (2), lateral (3), posterior (4), and anterior (5) views of an adult shell; ×2; Coral Unit, Hungry Hollow Member, Widder Formation, Collecting locality 3; W 2918.

Figs. 6-15 *Devonochonetes arkonensis* n. sp.

6-10. dorsal (6), ventral (7), lateral (8), posterior (9), and anterior (10) views of a paratype shell; ×4; Thedford Member, Widder Formation, Collecting locality 3; W 2916.

11-15. dorsal (11), ventral (12), lateral (13), posterior (14), and anterior (15) views of a paratype shell; ×4; Arkona Shale, Collecting locality 1; W 2917.

Fig. 16-17 *Strophodonta titan titan* Imbrie, 1959 ?

16. the exterior of an incomplete ventral shell, showing the large subsemicircular outline and coarse angular costella; 17. the lateral view of the same ventral shell; ×1.2; Coral Unit, Hungry Hollow Member, Widder Formation, Collecting locality 1; W 2913.

Pl. 2-7

Plate 2-8

Figs. 1-5 *Pentamerella* cf. *pavilionensis* (Hall, 1860)

1-5. dorsal (1), ventral (2), lateral (3), posterior (4), and anterior (5) views of an adult shell; ×2; Coral Unit, Hungry Hollow Member, Widder Formation, Hungry Hollow; UMMP 74034.

Figs. 6-12 *Pholidostrophia nacrea* (Hall, 1857)

6-10. dorsal (6), ventral (7), lateral (8), posterior (9), and anterior (10) views of an adult shell; ×2; Coral Unit, Hungry Hollow Member, Widder Formation, Collecting locality 5; W 2898.

11. dorsal internal view of an adult shell; ×4; Coral Unit, Hungry Hollow Member, Widder Formation, Collecting locality 5; W 2899.

12. Ventral internal view of an adult shell; ×4; Coral Unit, Hungry Hollow Member, Widder Formation, Collecting locality 5; W 2900.

Figs. 13-17 *Productella truncata* (Hall, 1857)

13-17. dorsal (13), ventral (14), lateral (15), posterior (16), and anterior (17) views of an adult shell; ×3; Arkona Shale, Hungry Hollow; UMMP 74036.

Pl. 2-8

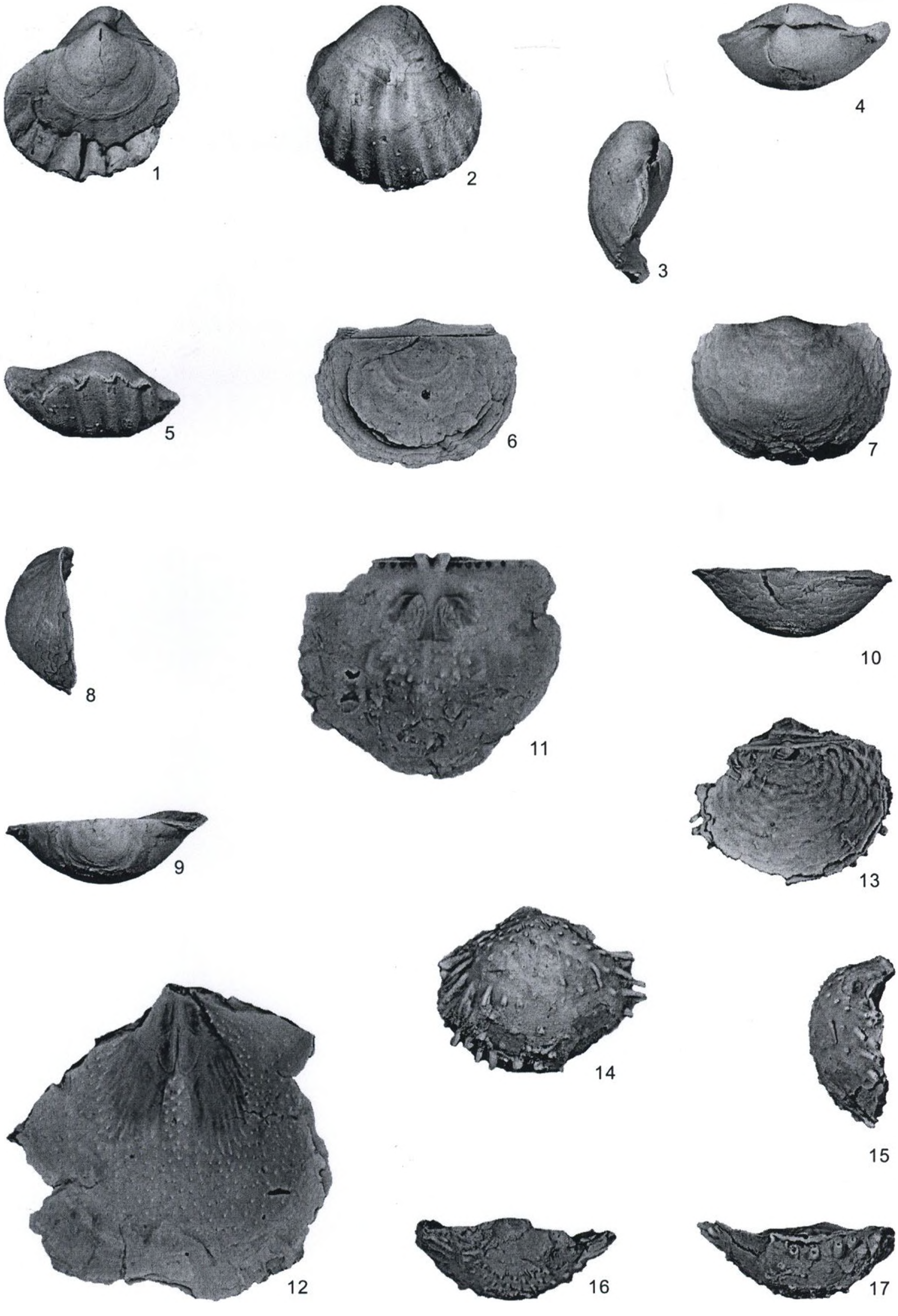


Plate 2-9

Figs. 1-5 *Floweria arctostriata* (Hall, 1843)

1-5. dorsal (1), ventral (2), lateral (3), posterior (4), and anterior (5) views of an adult shell; ×2; Arkona Shale, Collecting locality 6; W 2906.

Figs. 6-10 *Floweria* sp.

6-10. dorsal (6), ventral (7), lateral (8), posterior (9), and anterior (10) views of an adult shell; ×2; Coral Unit, Hungry Hollow Member, Widder Formation, Hungry Hollow; UMMP 74037.

Figs. 11-15 ? *Mediospirifer* sp.

11-15. dorsal (11), ventral (12), lateral (13), posterior (14), and anterior (15) views of an adult shell; ×1; Coral Unit, Hungry Hollow Member, Widder Formation; 2 miles (~3.22 km) east and 3/4 mile (~1.21 km) north of Arkona, Ontario; UMMP 74039.

Figs. 16-20 *Stenoscisma kernahani* (Whiteaves, 1898)

16-20. dorsal (16), ventral (17), lateral (18), posterior (19), and anterior (20) views of an adult shell; ×5; Coral Unit, Hungry Hollow Member, Widder Formation, Hungry Hollow; UMMP 74045.

Pl. 2-9

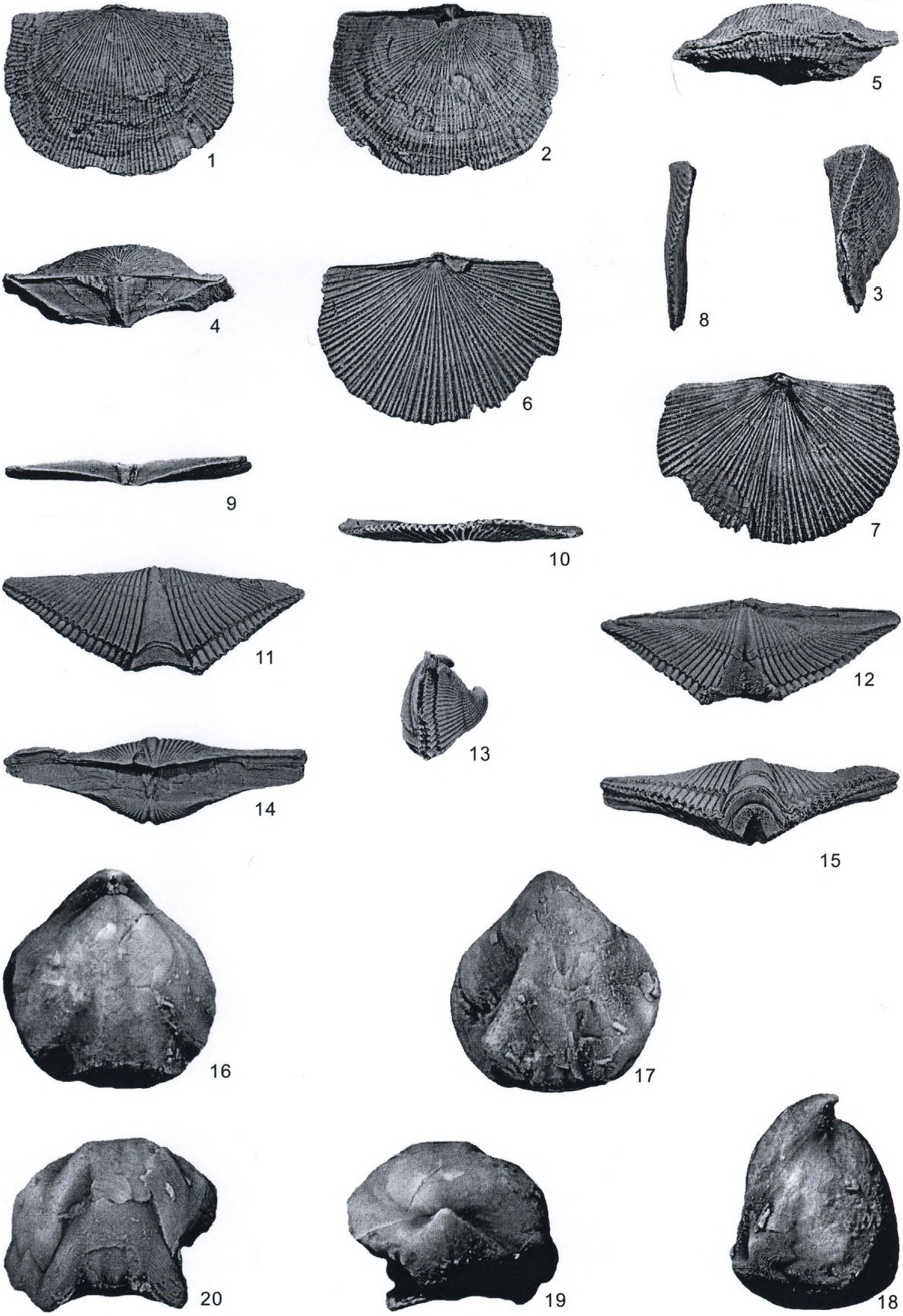


Plate 2-10

Figs. 1-7 *Rhipidomella vanuxemi* (Hall, 1857)

1-5. dorsal (1), ventral (2), lateral (3), posterior (4), and anterior (5) views of an adult shell; ×2; Ipperwash Limestone; Collecting locality 9; W 2901.

6. The interior of a dorsal valve; ×2.5; Coral Unit, Hungry Hollow Member, Widder Formation, Collecting locality 1; W 2902.

7. The interior of a ventral valve, showing the form of the muscular impression; × 1.5; Coral Unit, Hungry Hollow Member, Widder Formation, Collecting locality 1; W 2903.

Figs. 8-13 *Rhipidomella penelope* (Hall, 1860)

8-12. dorsal (8), ventral (9), lateral (10), posterior (11), and anterior (12) views of an adult shell; ×1.5; Ipperwash Limestone, Collecting locality 9; W 2904.

13. The interior of a ventral valve, showing the form of the muscular impression; ×2; Coral Unit, Hungry Hollow Member, Widder Formation, Collecting locality 5; W 2905.

Pl. 2-10

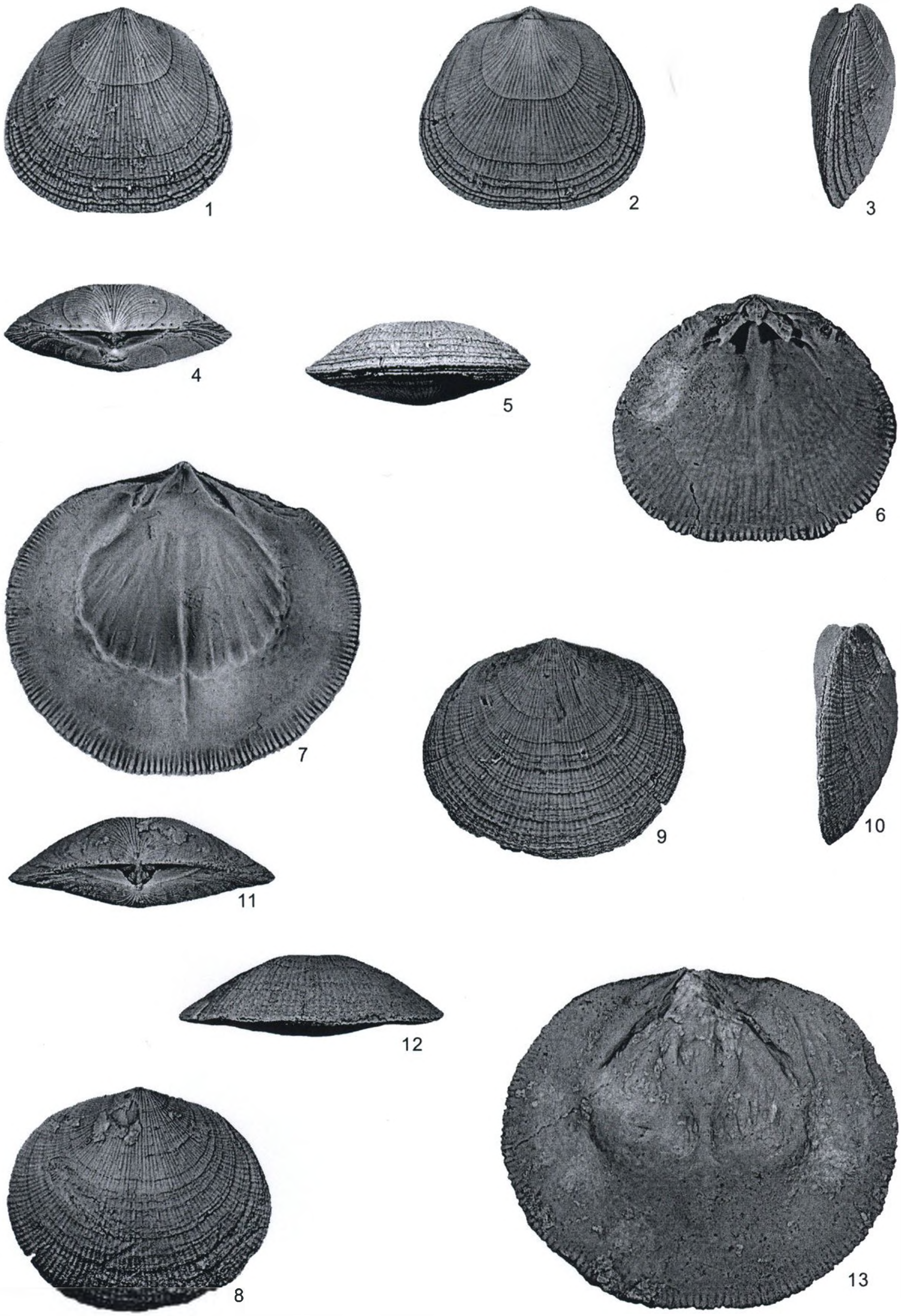


Plate 2-11

Figs. 1-5 *Callipleura nobilis* (Hall, 1860)

1-5. dorsal (1), ventral (2), lateral (3), posterior (4), and anterior (5) views of an adult shell; ×1.2; Hungry Hollow Member, Widder Formation; Hungry Hollow; UMMP 35799A.

Figs. 6-15 *Camarotoechia thedfordensis* Whiteaves, 1898

6-10. dorsal (6), ventral (7), lateral (8), posterior (9), and anterior (10) views of a juvenile shell showing length greater than width in the majority of juvenile specimens; ×5; Coral Unit, Hungry Hollow Member, Widder Formation, Collecting locality 5; W 2860.

11-15. dorsal (11), ventral (12), lateral (13), posterior (14), and anterior (15) views of an adult shell showing width greater than length in the majority of mature specimens; ×5; Coral Unit, Hungry Hollow Member, Widder Formation, Collecting locality 5; W 2859.

Figs. 16-25 *Cryptonella attenuata* (Whiteaves, 1898)

16-20. dorsal (16), ventral (17), lateral (18), posterior (19), and anterior (20) views of an adult shell showing a somewhat broader form; ×6; Tile Yard, Thedford; UMMP 74042.

21-25. dorsal (21), ventral (22), lateral (23), posterior (24), and anterior (25) views of an adult shell with an elongated shape in the majority of specimens; ×6; Coral Unit, Hungry Hollow Member, Widder Formation, Collecting locality 5; W 2866.

Pl. 2-11

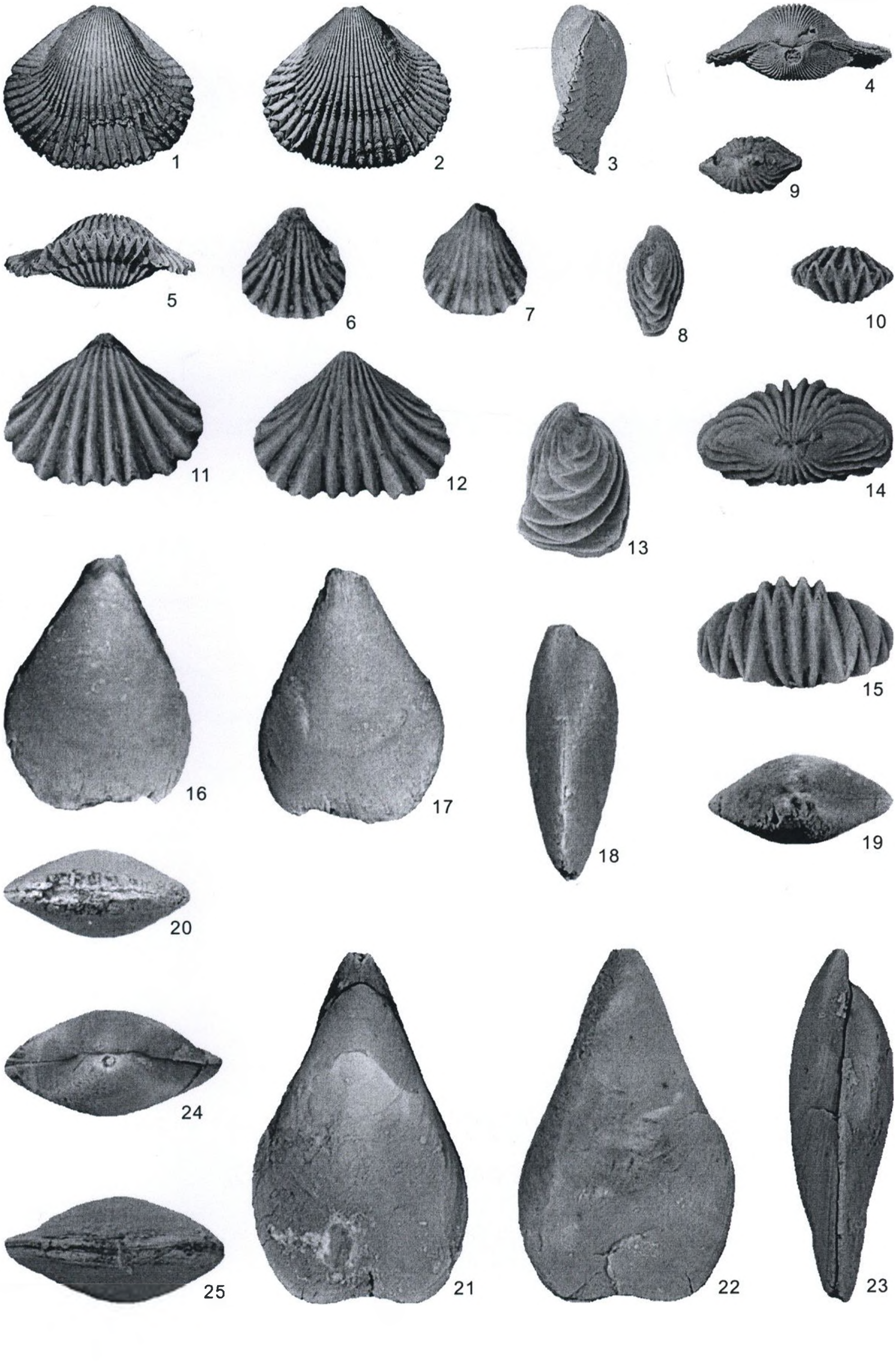


Plate 2-12

Figs. 1-5 *Athyris vittata* Hall, 1860

1-5. dorsal (1), ventral (2), lateral (3), posterior (4), and anterior (5) views of an adult shell; ×2; Thedford Member, Widder Formation, Collecting locality 3; W 2850.

Figs. 6-20 *Athyris spiriferoides* (Eaton, 1832)

6-10. dorsal (6), ventral (7), lateral (8), posterior (9), and anterior (10) views of an adult shell with slightly lamellose growth lines; ×2; Rock Glen Submember, Petrolia Member, Widder Formation, Collecting locality 4; W 2851.

11-15. dorsal (11), ventral (12), lateral (13), posterior (14), and anterior (15) views of an adult shell, showing a strongly lamellose surface; ×2; Ipperwash Limestone, Collecting locality 9; W 2852.

16-20. dorsal (16), ventral (17), lateral (18), posterior (19), and anterior (20) views of an adult shell, showing deformed anterolateral part of the shell in some specimens; ×1.5; Coral Unit, Hungry Hollow Member, Widder Formation, Collecting locality 5; W 2853.

Pl. 2-12

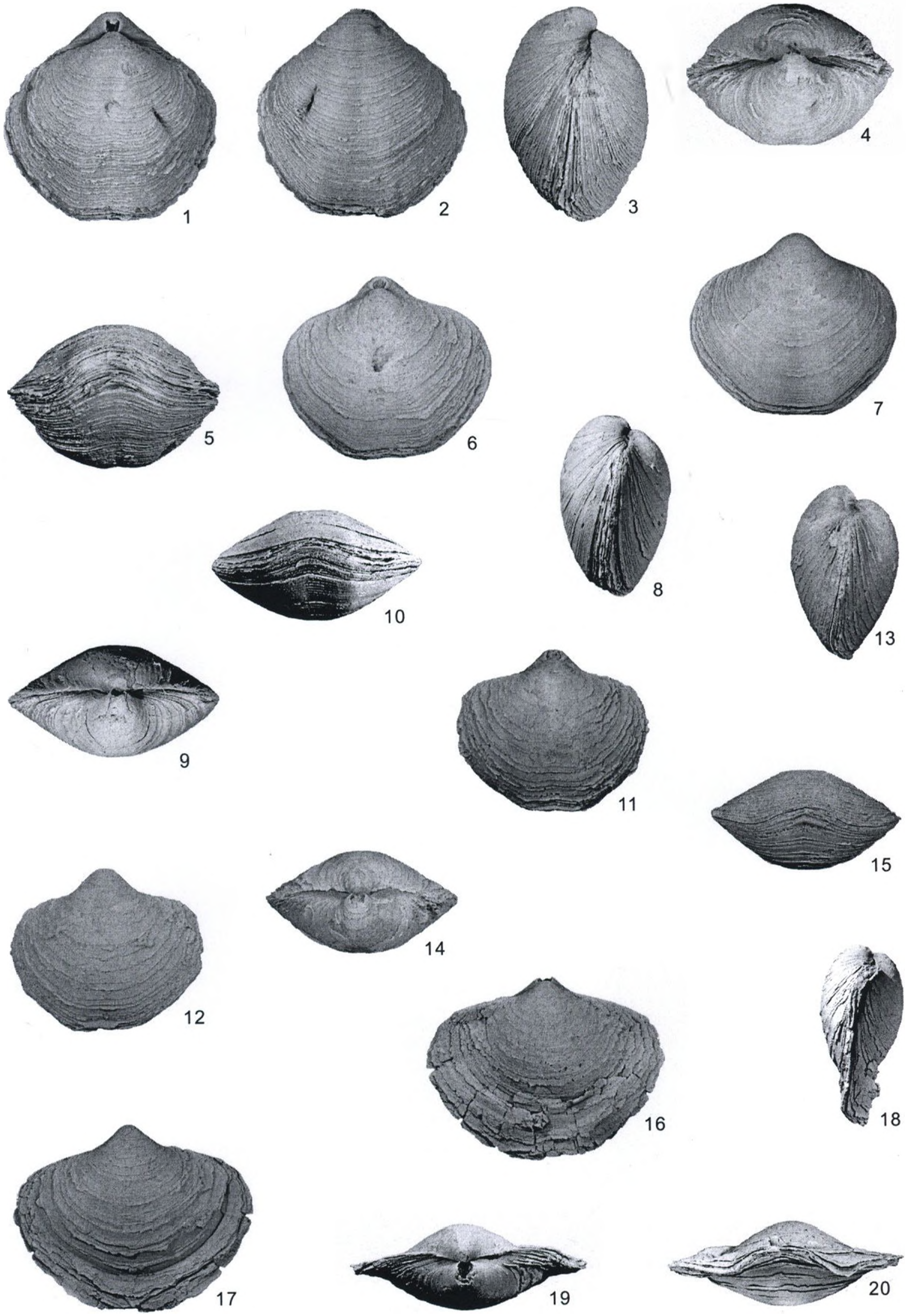


Plate 2-13

Figs. 1-5 *Leiorhynchus laura* (Billings, 1860)

1-5. dorsal (1), ventral (2), lateral (3), posterior (4), and anterior (5) views of an adult shell with a somewhat broad form; ×2; Rock Glen Submember, Petrolia Member, Widder Formation, Collecting locality 4; W 2873.

Figs. 6-20 *Nucleospira concinna* (Hall, 1843)

6-10. dorsal (6), ventral (7), lateral (8), posterior (9), and anterior (10) views of an adult shell with rare concentrated lamellose growth lines on the surface; ×3; Coral Unit, Hungry Hollow Member, Widder Formation, Collecting locality 5; W 2892.

11-15. dorsal (11), ventral (12), lateral (13), posterior (14), and anterior (15) views of an adult shell with more growth lines on the surface; ×3; Coral Unit, Hungry Hollow Member, Widder Formation, Collecting locality 5; W 2893.

16-20. dorsal (16), ventral (17), lateral (18), posterior (19), and anterior (20) views of an adult shell with a somewhat flattened form; ×3; Coral Unit, Hungry Hollow Member, Widder Formation, Collecting locality 5; W 2894.

Pl. 2-13

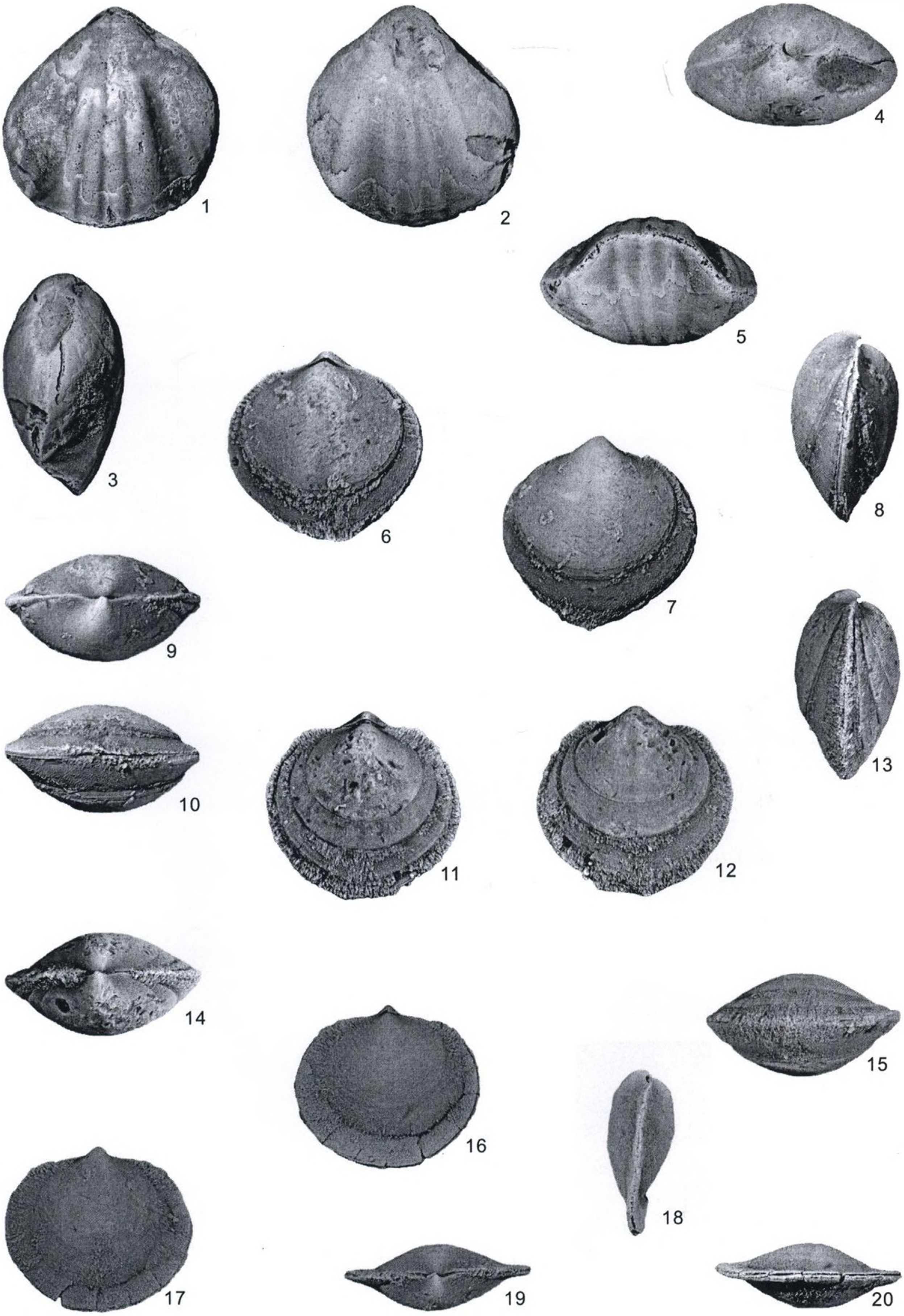


Plate 2-14

Figs. 1-10 *Atrypa* (*Atrypa*) *reticularis* (Linnaeus, 1758)

1-5. dorsal (1), ventral (2), lateral (3), posterior (4), and anterior (5) views of a juvenile shell; ×1.5; Coral Unit, Hungry Hollow Member, Widder Formation, Collecting locality 1; W 2854.

6-10. dorsal (6), ventral (7), lateral (8), posterior (9), and anterior (10) views of an adult shell; ×1.5; Coral Unit, Hungry Hollow Member, Widder Formation, Collecting locality 5; W 2855.

Figs. 11-15 *Pseudoatrypa* cf. *devoniana* (Webster, 1921)

11-15. dorsal (11), ventral (12), lateral (13), posterior (14), and anterior (15) views of an adult shell; ×1.5; Ipperwash Limestone, Collecting locality 9; W 2861.

Figs. 16-20 *Ambocoelia tuberculata* Goldman & Mitchell, 1990

16-20. dorsal (16), ventral (17), lateral (18), posterior (19), and anterior (20) views of an adult shell; ×5; Coral Unit, Hungry Hollow Member, Widder Formation, Collecting locality 1; W 2856.

Pl. 2-14

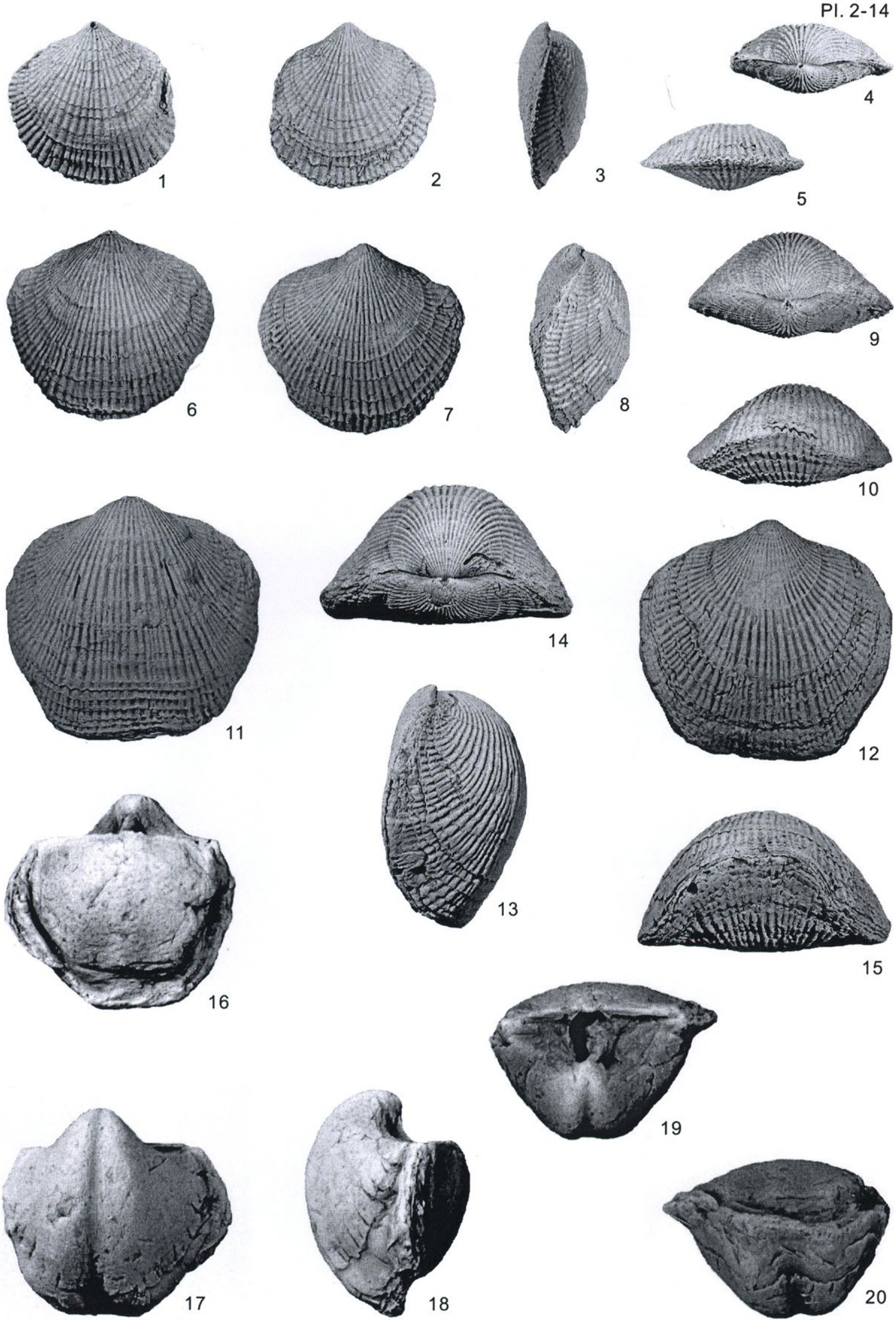


Plate 2-15

Figs. 1-10 *Cranaena romingeri* (Hall, 1863)

1-5. dorsal (1), ventral (2), lateral (3), posterior (4), and anterior (5) views of an adult shell with an elongated shape; ×3; Coral Unit, Hungry Hollow Member, Widder Formation, Collecting locality 3; W 2862.

6-10. dorsal (6), ventral (7), lateral (8), posterior (9), and anterior (10) views of an adult shell showing a somewhat broader form; ×3; Coral Unit, Hungry Hollow Member, Widder Formation, Collecting locality 5; W 2864.

Figs. 11-15 *Cranaena harmonia* (Hall, 1867)

11-15. dorsal (11), ventral (12), lateral (13), posterior (14), and anterior (15) views of an adult shell; ×3; Coral Unit, Hungry Hollow Member, Widder Formation, Collecting locality 3; W 2865.

Figs. 16-20 *Charionella scitula* (Hall, 1843)

16-20. dorsal (16), ventral (17), lateral (18), posterior (19), and anterior (20) views of an adult shell; ×4; Arkona Shale, Collecting locality 2; W 2922.

Pl. 2-15

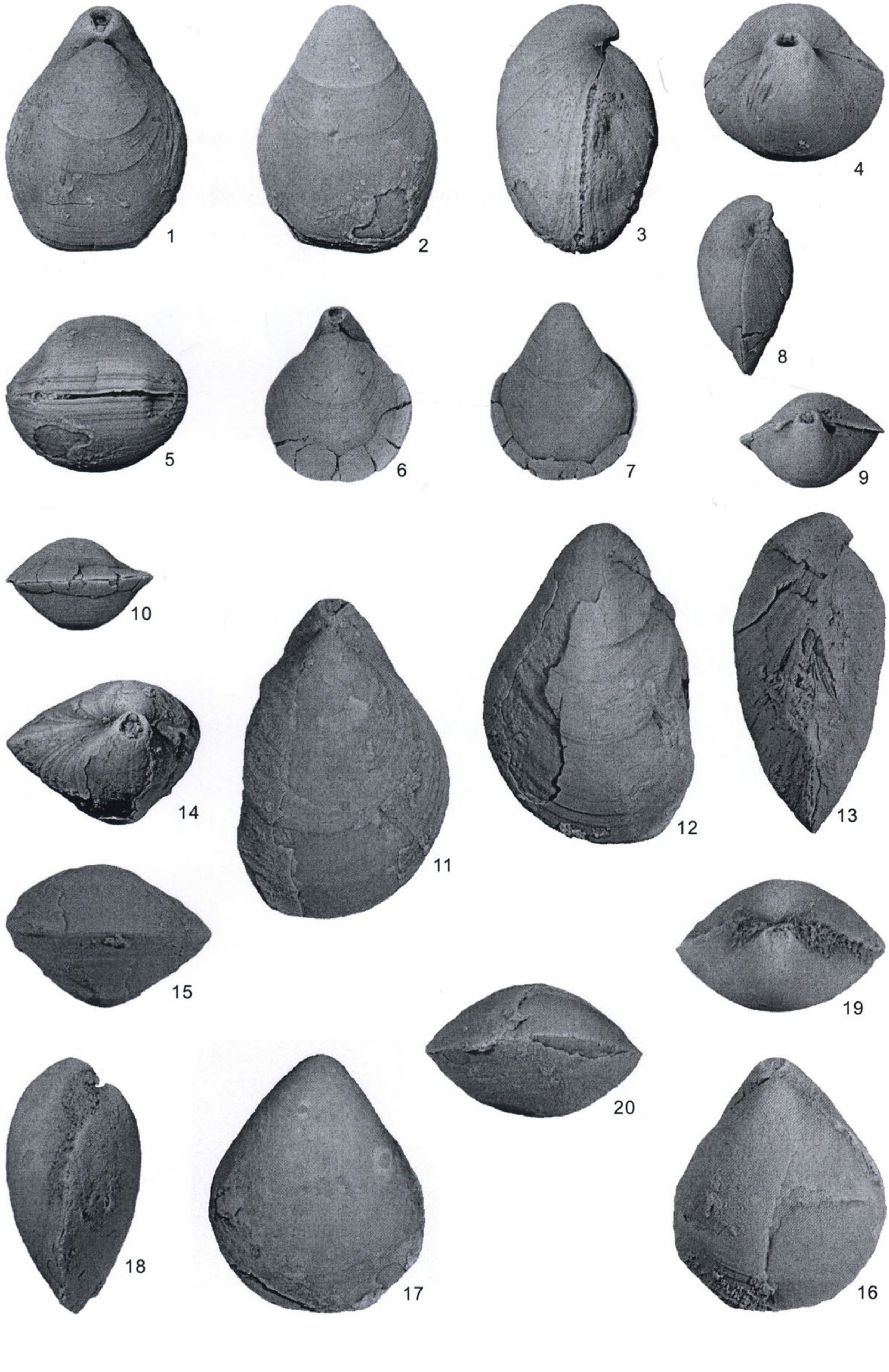


Plate 2-16

Figs. 1-15 *Parazyga* cf. *hirsuta* (Hall, 1857)

1-5. dorsal (1), ventral (2), lateral (3), posterior (4), and anterior (5) views of a juvenile shell; ×3; Coral Unit, Hungry Hollow Member, Widder Formation, Collecting locality 3; W 2897.

6-10. dorsal (6), ventral (7), lateral (8), posterior (9), and anterior (10) views of an adult shell with uniplicate anterior commissure; ×2; Coral Unit, Hungry Hollow Member, Widder Formation, Collecting locality 3; W 2896.

11-15. dorsal (11), ventral (12), lateral (13), posterior (14), and anterior (15) views of an adult shell, showing rectimarginate anterior commissure; ×2.5; Coral Unit, Hungry Hollow Member, Widder Formation, Collecting locality 5; W 2895.

Figs. 16-20 *Pentagonia bisulcata* (Cooper) ?

16-20. dorsal (16), ventral (17), lateral (18), posterior (19), and anterior (20) views of an adult shell; ×2; Coral Unit, Hungry Hollow Member, Widder Formation; Hungry Hollow; UMMP 74030.

Pl. 2-16

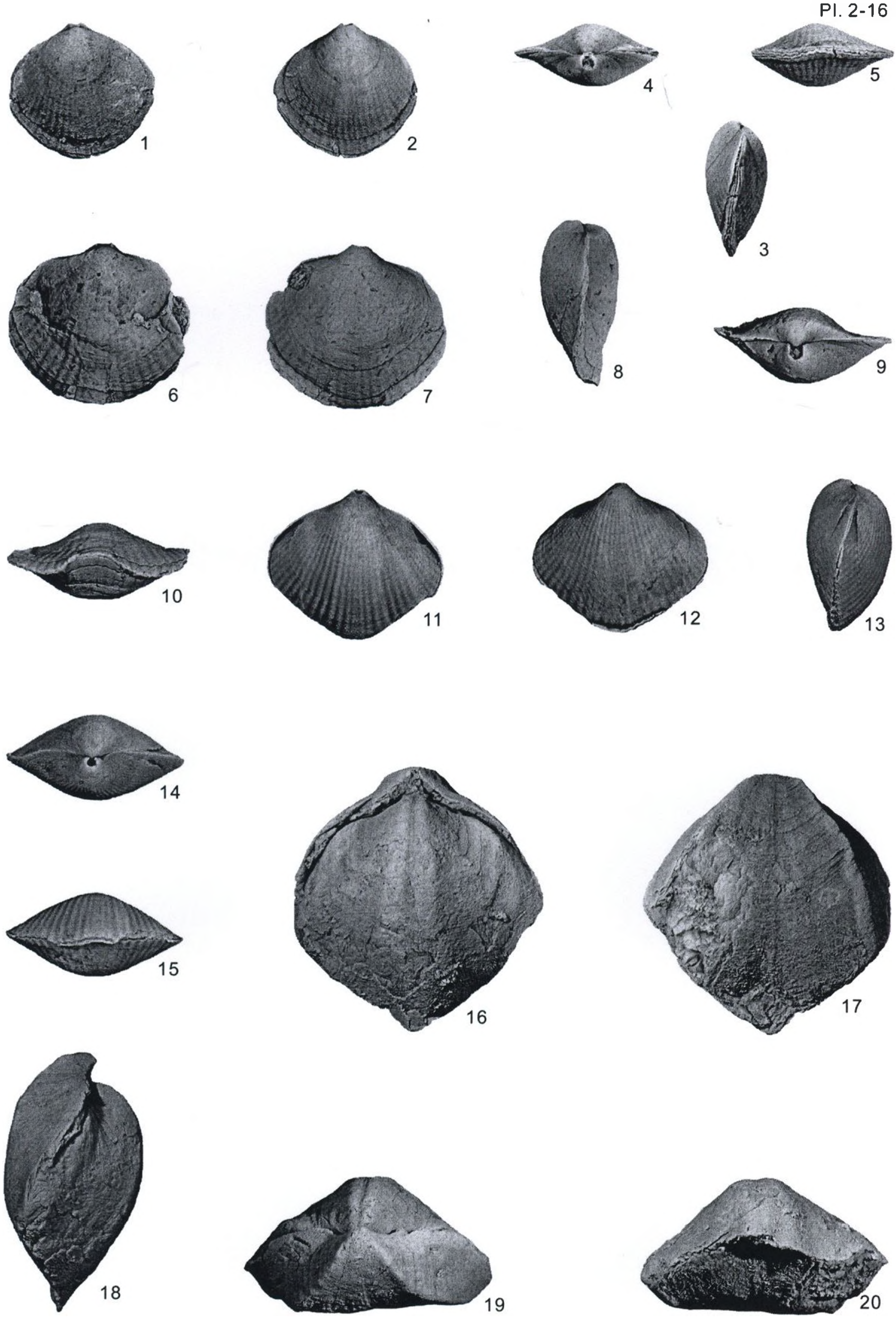


Plate 2-17

Figs. 1-5 *Spinocyrtia ravenswoodensis* Ehlers & Wright, 1955

1-5. dorsal (1), ventral (2), lateral (3), posterior (4), and anterior (5) views of an adult shell; ×1; Stony Point Submember, Petrolia Member, Widder Formation, field near Ravenswood, Basanquet Township, Lambton County, Ontario; UMMP 74038.

Figs. 6-10 *Spinocyrtia granulosa* (Conrad, 1839)

6-10. dorsal (6), ventral (7), lateral (8), posterior (9), and anterior (10) views of an adult shell; ×1.2; Stony Point Submember, Petrolia Member, Widder Formation, 14 miles (22.53 km) northwest of Thedford, Ontario; UMMP 35838A.

Pl. 2-17

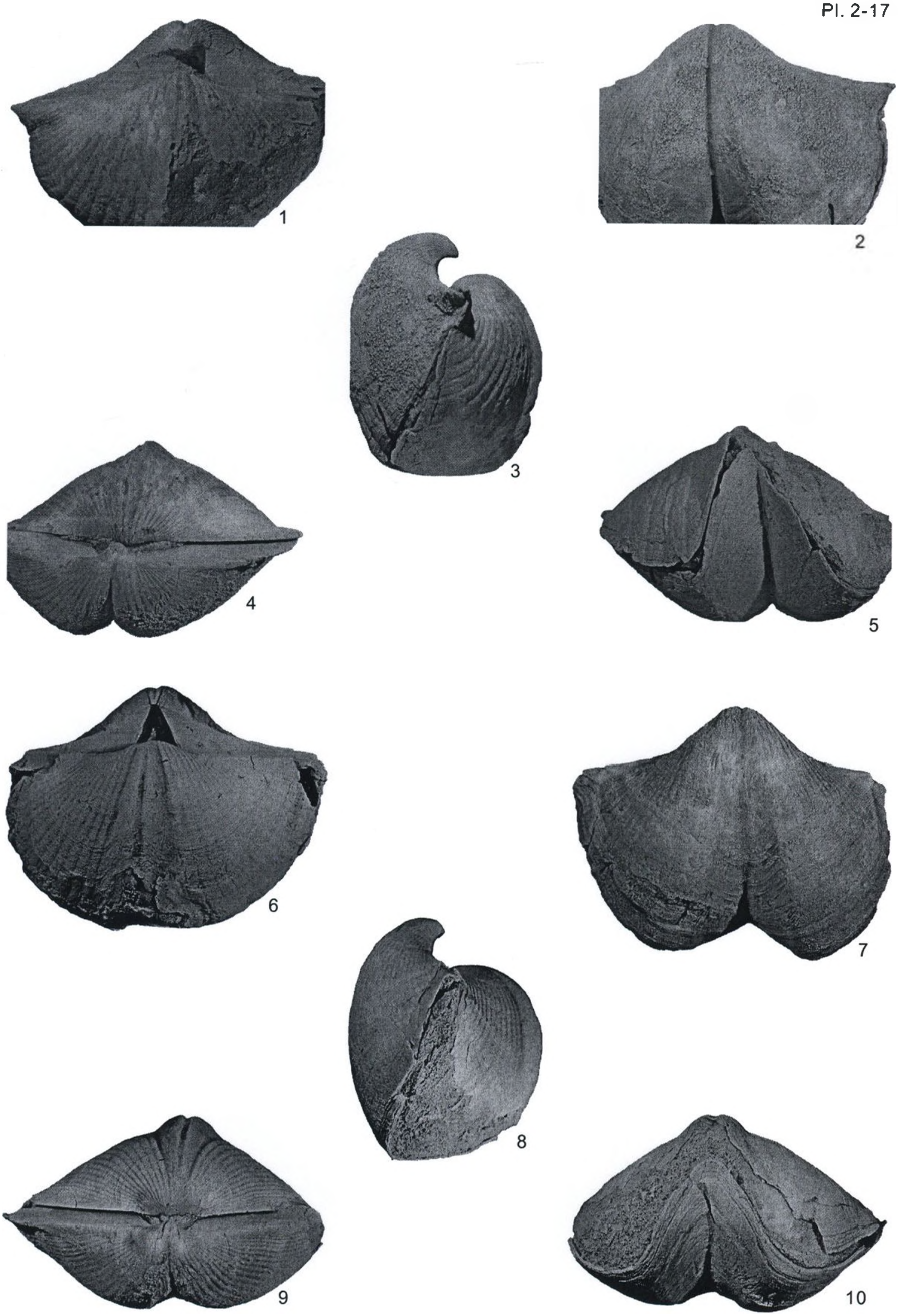


Plate 2-18

Figs. 1-5 *Spinocyrtia mourantae* Ehlers& Wright, 1955

1-5. dorsal (1), ventral (2), lateral (3), posterior (4), and anterior (5) views of an adult shell; ×1.2; Arkona Shale; Lot 8, Arkona, Ontario; UMMP 74043.

Figs. 6-10 *Spinocyrtia parvigranulata* Ehlers& Wright, 1955

6-10. dorsal (6), ventral (7), lateral (8), posterior (9), and anterior (10) views of an adult shell; × 1.2; Golden Creek Submember, Petrolia Member, Widder Formation, Golden Creek, Ontario; UMMP 74044.

Pl. 2-18

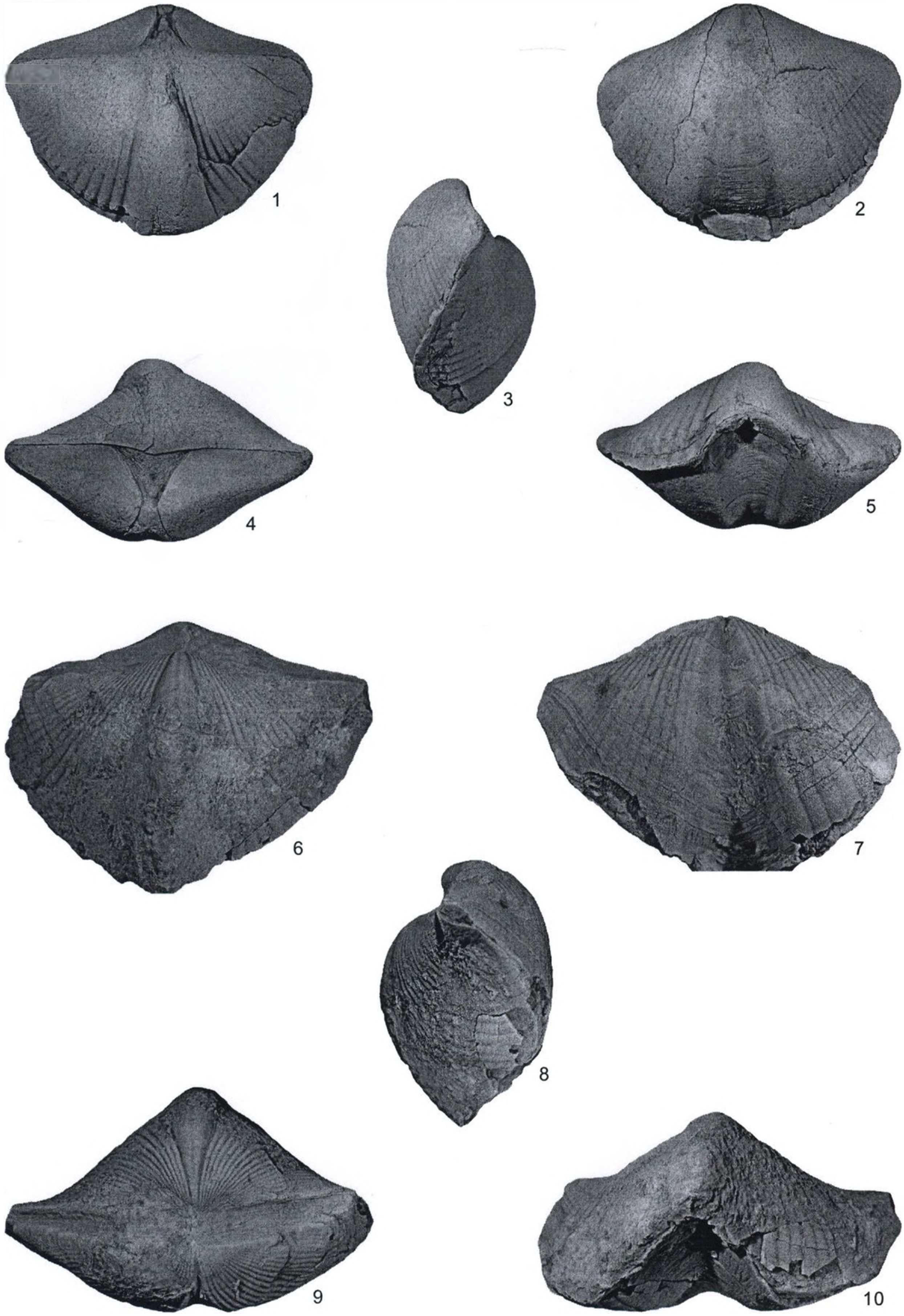


Plate 2-19

Figs. 1-20 *Mucrospirifer mucronatus* (Conrad, 1841)

1-5. dorsal (1), ventral (2), lateral (3), posterior (4), and anterior (5) views of an adult shell; × 1.2; Arkona Shale, Collecting locality 2; W 2883.

6-10. dorsal (6), ventral (7), lateral (8), posterior (9), and anterior (10) views of an adult shell; × 1.2; Arkona Shale, Collecting locality 10; W 2885.

11-15. dorsal (11), ventral (12), lateral (13), posterior (14), and anterior (15) views of an adult shell; × 1.2; Arkona Shale, Collecting locality 10; W 2886.

16-20. dorsal (16), ventral (17), lateral (18), posterior (19), and anterior (20) views of an adult shell; × 1.2; Arkona Shale, Collecting locality 2; W 2887.

Pl. 2-19

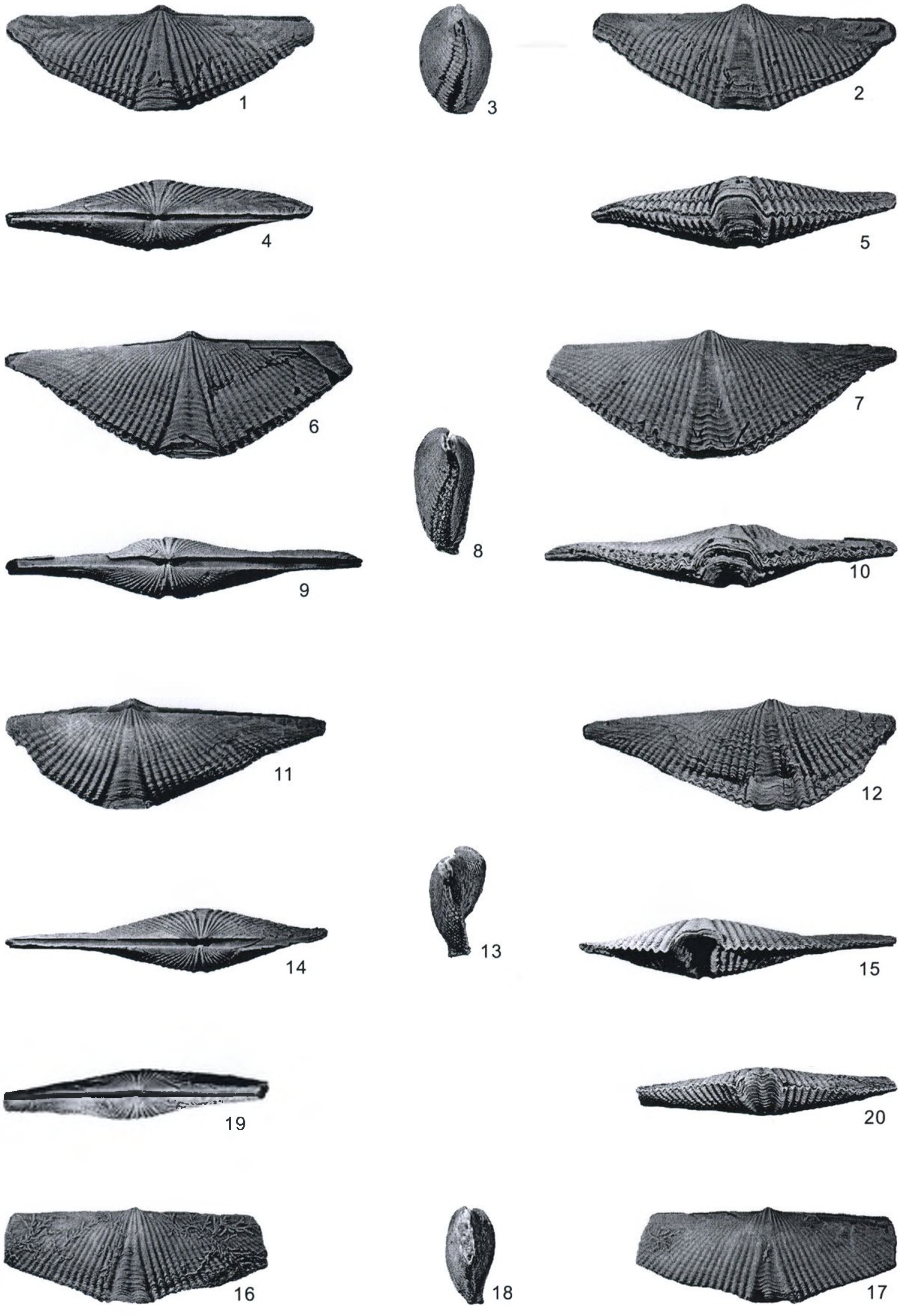


Plate 2-20

Figs. 1-15 *Mucrospirifer mucronatus* (Conrad, 1841)

1-5. dorsal (1), ventral (2), lateral (3), posterior (4), and anterior (5) views of an adult shell; ×1.5; Thedford Member, Widder Formation, Collecting locality 3; W 2884.

6-10. dorsal (6), ventral (7), lateral (8), posterior (9), and anterior (10) views of an adult shell; ×2.5; Rock Glen Submember, Petrolia Member, Widder Formation, Collecting locality 10; W 2888.

11-15. dorsal (11), ventral (12), lateral (13), posterior (14), and anterior (15) views of an adult shell; ×1.5; Thedford Member, Widder Formation, Collecting locality 3; W 2889.

Pl. 2-20

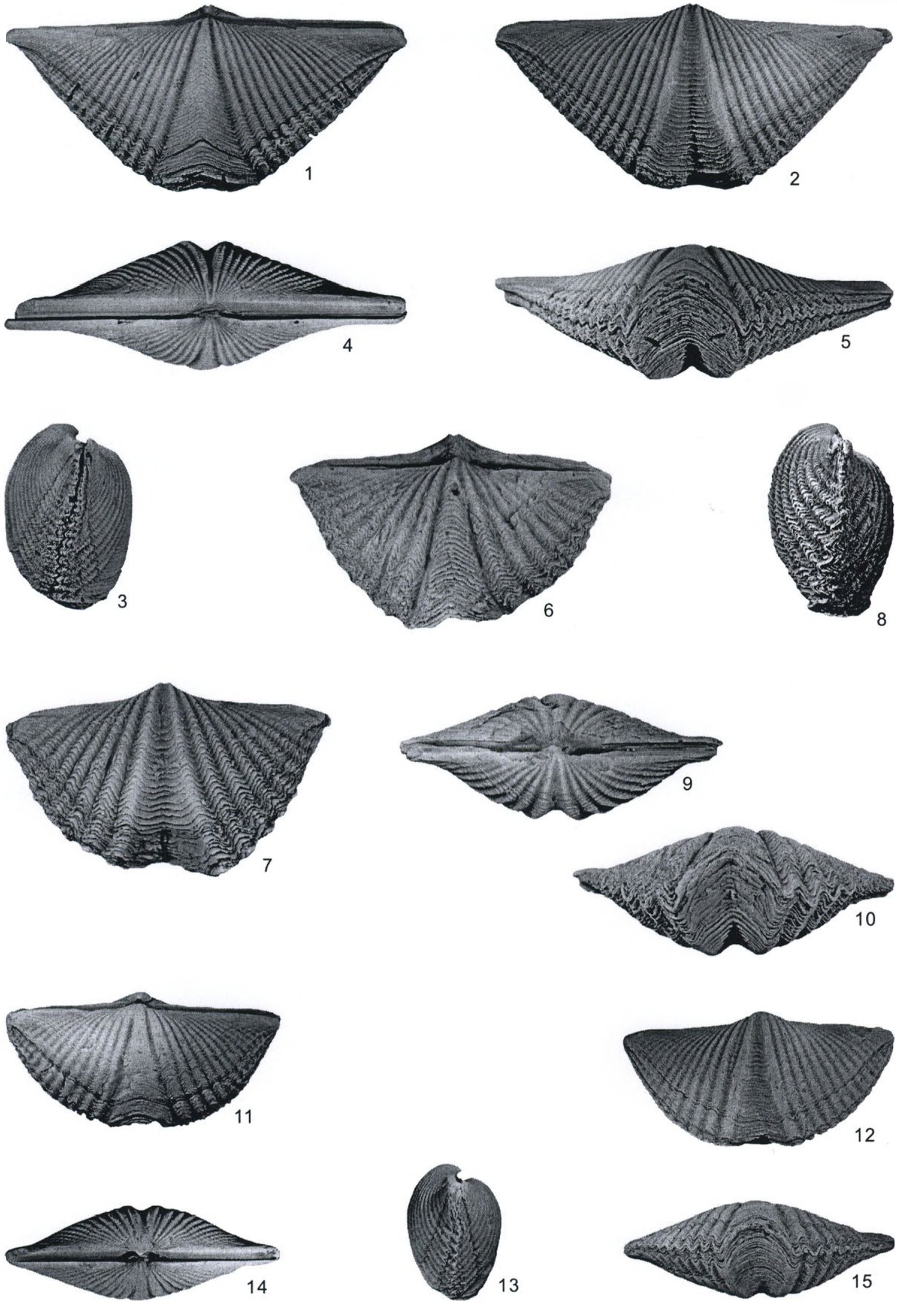


Plate 2-21

Figs. 1-20 *Mucrospirifer mucronatus* (Conrad, 1841)

1-5. dorsal (1), ventral (2), lateral (3), posterior (4), and anterior (5) views of an adult shell; ×1.2; Golden Creek Submember, Petrolia Member, Widder Formation, Collecting locality 7; W 2875.

6-10. dorsal (6), ventral (7), lateral (8), posterior (9), and anterior (10) views of an adult shell; × 1.2; Golden Creek Submember, Petrolia Member, Widder Formation, Collecting locality 7; W 2876.

11-15. dorsal (11), ventral (12), lateral (13), posterior (14), and anterior (15) views of an adult shell; ×1.2; Golden Creek Submember, Petrolia Member, Widder Formation, Collecting locality 7; W 2877.

16-20. dorsal (16), ventral (17), lateral (18), posterior (19), and anterior (20) views of an adult shell; ×1.2; Golden Creek Submember, Petrolia Member, Widder Formation, Collecting locality 7; W 2878.

Pl. 2-21

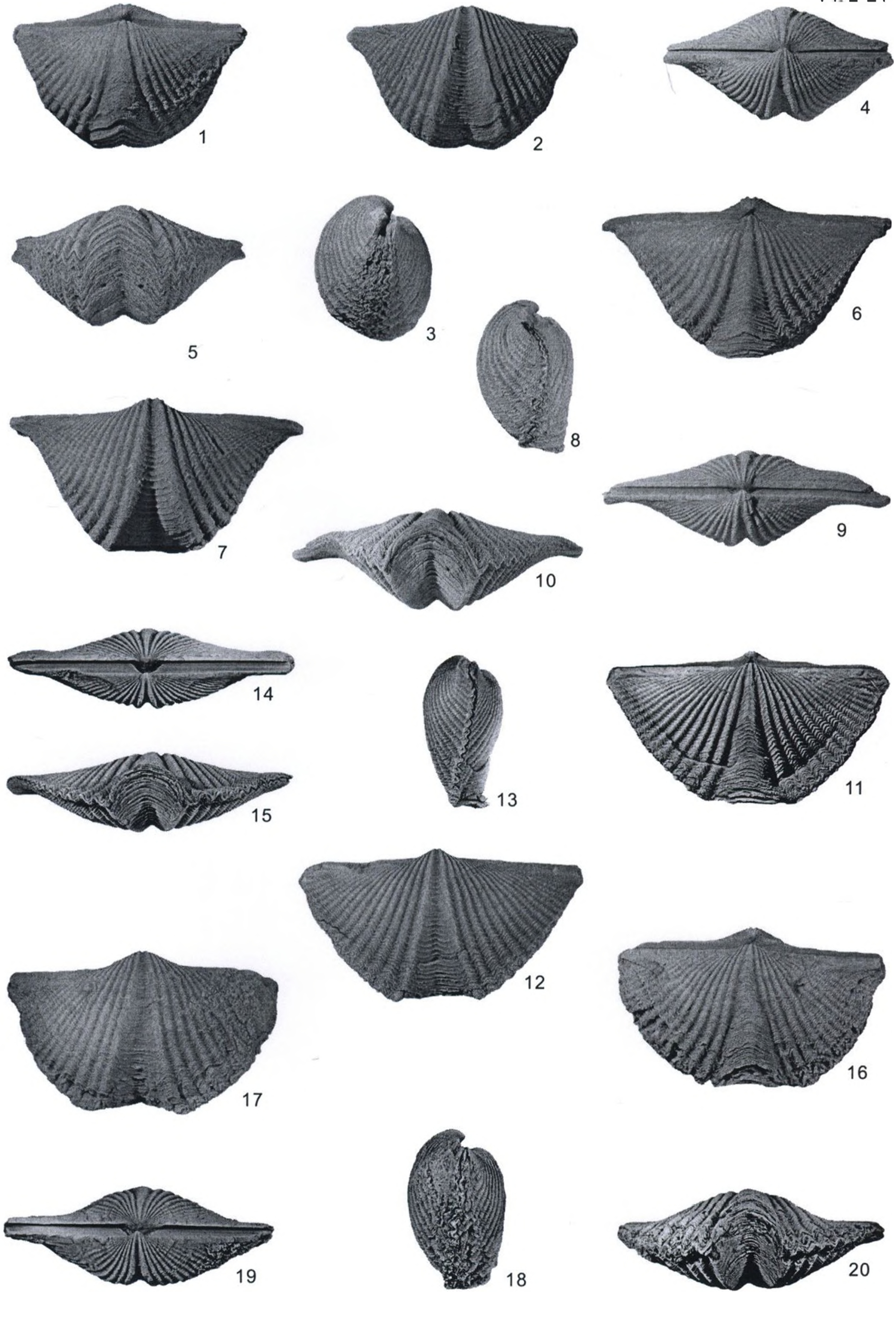


Plate 2-22

Figs. 1-20 *Mucrospirifer mucronatus* (Conrad, 1841)

1-5. dorsal (1), ventral (2), lateral (3), posterior (4), and anterior (5) views of an adult shell; ×1.2; Arkona Shale, Collecting locality 10; W 2881.

6-10. dorsal (6), ventral (7), lateral (8), posterior (9), and anterior (10) views of an adult shell; ×1.2; Thedford Member, Widder Formation; Collecting locality 3; W 2879.

11-15. dorsal (11), ventral (12), lateral (13), posterior (14), and anterior (15) views of an adult shell; ×1.2; Rock Glen Submember, Petrolia Member, Widder Formation, Collecting locality 10; W 2882.

16-20. dorsal (16), ventral (17), lateral (18), posterior (19), and anterior (20) views of an adult shell; ×1.2; Stony Point Submember, Petrolia Member, Widder Formation, Collecting locality 8; W 2880.

Pl. 2-22

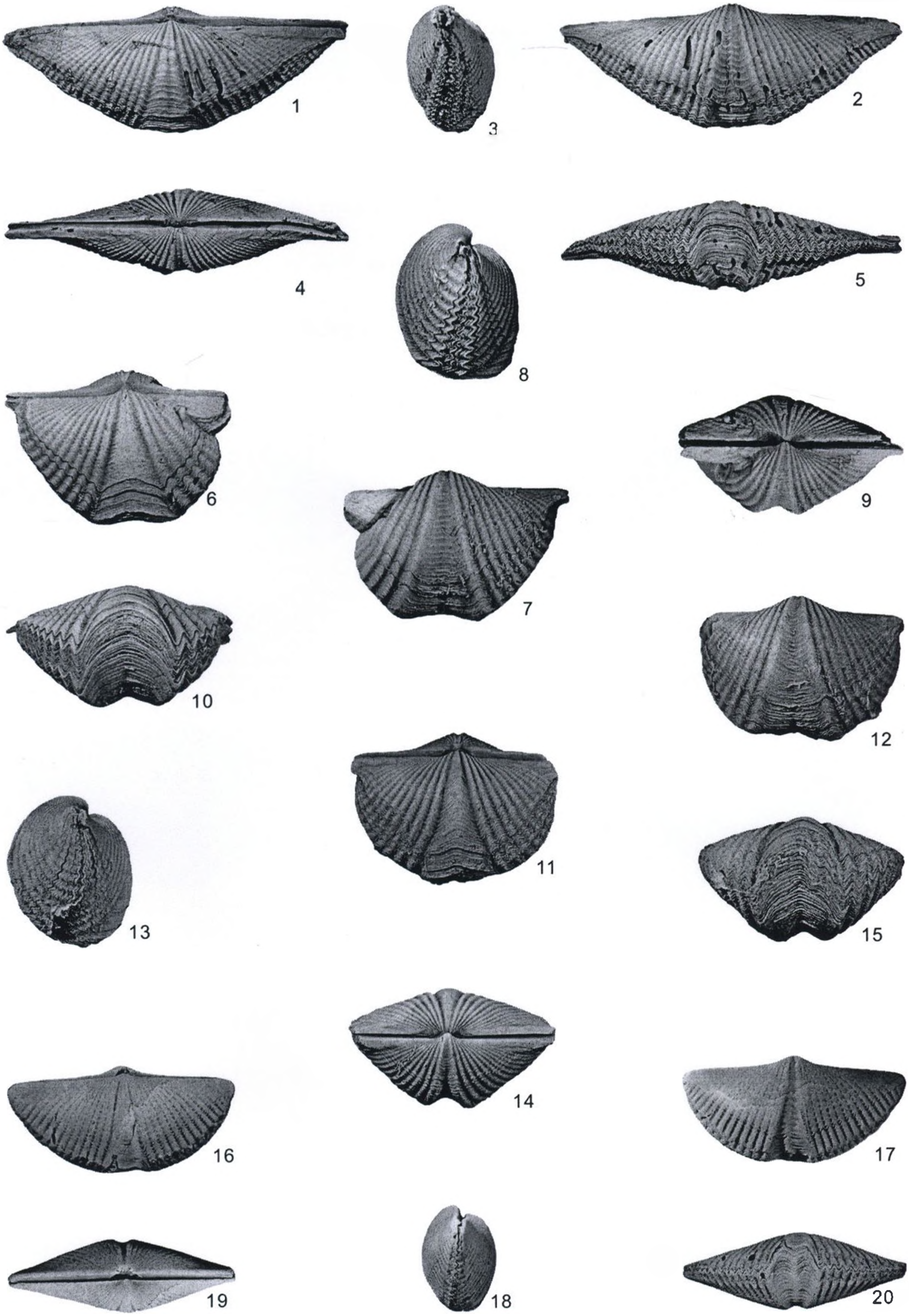


Plate 2-23

Figs. 1-10 *Mucrospirifer mucronatus* (Conrad, 1841)

1-5. dorsal (1), ventral (2), lateral (3), posterior (4), and anterior (5) views of an adult shell; ×1.5; Silica Formation, Lucas County, Ohio; W 2890.

6-10. dorsal (6), ventral (7), lateral (8), posterior (9), and anterior (10) views of an adult shell; ×1.5; Silica Formation; Lucas County, Ohio; W 2891.

Pl. 2-23

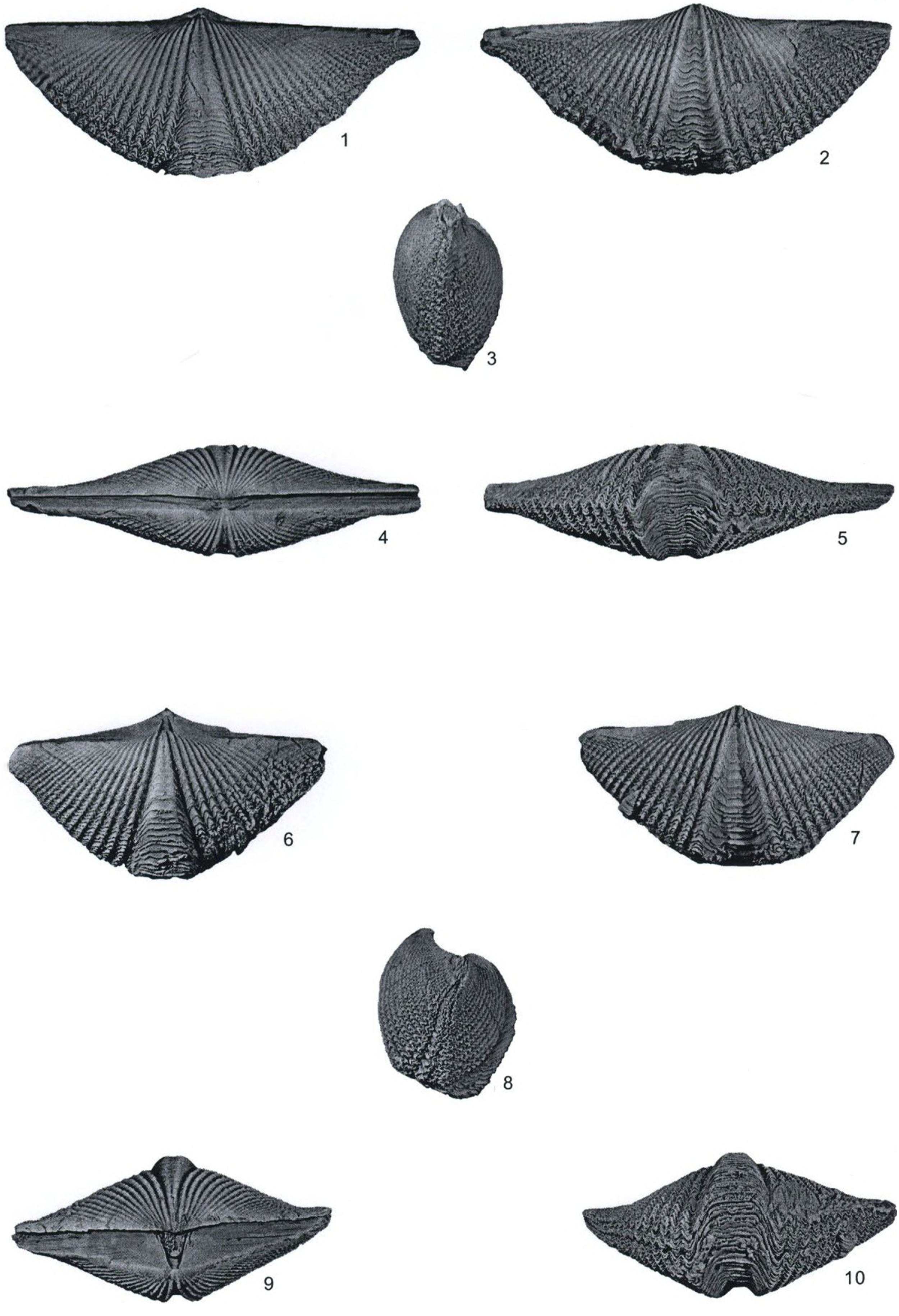


Plate 2-24

Figs. 1-10 *Cyrtina arkonensis* Ehlers & Wright, 1975

1-5. dorsal (1), ventral (2), lateral (3), posterior (4), and anterior (5) views of an adult shell; ×2; Arkona Shale, Collecting locality 4; W 2871.

6-10. dorsal (6), ventral (7), lateral (8), posterior (9), and anterior (10) views of an adult shell with more delicate costae on surface; ×2; Arkona Shale, Collecting locality 2; W 2869.

Figs. 11-15 *Cyrtina angularis* Ehlers & Wright, 1975

11-15. dorsal (11), ventral (12), lateral (13), posterior (14), and anterior (15) views of an adult shell, showing deep subangular sulcus with a prominent median depression, and a rounded broad fold with a shallow median depression median depression in posterior part; ×2; Golden Creek Submember, Petrolia Member, Widder Formation, Collecting locality 7; W 2868.

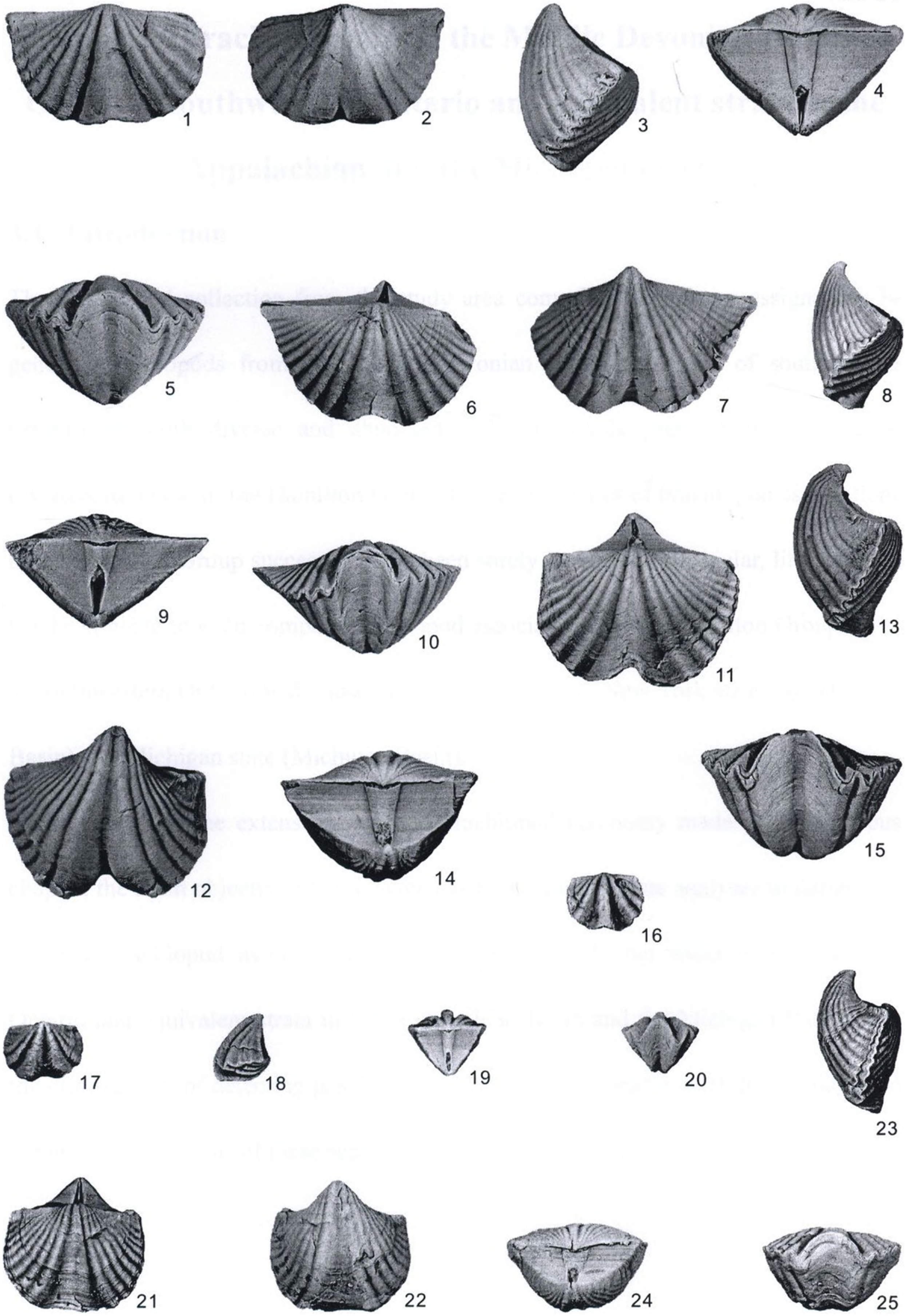
Figs. 16-20 *Cyrtina coultisorum* Ehlers & Wright, 1975

16-20. dorsal (16), ventral (17), lateral (18), posterior (19), and anterior (20) views of an adult shell; ×2; Coral Unit, Hungry Hollow Member, Widder Formation; Collecting locality 3; W 2870.

Figs. 21-25 *Cyrtina staufferi* Wright & Wright, 1963

21-25. dorsal (21), ventral (22), lateral (23), posterior (24), and anterior (25) views of an adult shell; ×2; Stony Point Submember, Petrolia Member, Widder Formation; Stony Point, shore of Lake Huron, Provincial Park, Ontario; UMMP74031.

Pl. 2-24



Chapter 3: Brachiopods from the Middle Devonian Hamilton Group of southwestern Ontario and equivalent strata in the Appalachian and the Michigan basins

3.1 Introduction

The brachiopod collection from the study area comprises 50 species assigned to 34 genera. Brachiopods from the Middle Devonian Hamilton Group of southwestern Ontario are both diverse and abundant and collectively predominate the marine invertebrate fauna of the Hamilton Group. However, studies of brachiopod associations in the Hamilton Group succession have been sorely lacking. In particular, little attempt has been made to even compare brachiopod associations of the Hamilton Group strata of southwestern Ontario with those of equivalent strata in New York state (Appalachian Basin) and Michigan state (Michigan Basin).

Drawing from the extensive work on brachiopod taxonomy made in the previous chapter, the main objective of this chapter is to use multivariate analyses to define and compare brachiopod associations from the Hamilton Group strata in southwestern Ontario and equivalent strata in the Appalachian Basin and the Michigan Basin, with the ultimate aim of detecting possible patterns of temporal and spatial differentiation in the brachiopod faunas of these separate basins and paleogeographic regions.

3.2 Methods

3.2.1 Cluster Analyses and Principal Component Analysis

To compare and analyze the brachiopod associations of the Hamilton Group from the study area (southwestern Ontario) with those of equivalent strata in the Appalachian Basin and the Michigan Basin, a binary (i.e. present or absence of a taxon) dataset of all brachiopod faunas from various locations of these regions was compiled. In this binary dataset, taxa were treated as variables while the sample localities were treated as cases. The resulting dataset was subjected to multivariate analyses using PAST 1.90 (Hammer and Harper, 2006, 2007). Q-mode (taxa as variables), R-mode (localities/ages as variables) cluster analyses (CA) were then performed using Ward's method (for details, see Ward, 1963). The same dataset was used also for a principal component analysis (PCA). The variance-covariance algorithm of PAST was used for the PCA. The PCA scattergram was found to correspond well to the pattern of the cluster dendrogram in most cases.

3.2.2 Similarity Indices

In order to quantifiably measure the similarity among brachiopod associations from the Hamilton Group of southwestern Ontario and those of contemporary strata in the Appalachian and Michigan basins, four common similarity indices were used.

3.2.2.1 Jaccard Similarity Index

The Jaccard similarity index (Jaccard, 1912), JSI, is defined as follows:

$$JSI = M/(M+N)$$

M is the number of species that are present in both samples, and N is the total number of all remaining species (i.e., those species present in one or the other, but not both samples).

By using the Jaccard similarity index, absences in both samples are ignored. When one of the two samples is much smaller than the other, the value of this index is always small (Hammer and Harper, 2006).

3.2.2.2 Dice Similarity Index

The Dice similarity index (Dice, 1945), DSI, also known as the coefficient of community (Hammer and Harper, 2006), is defined as follows:

$$DSI = M/((2M+N)/2) = 2M/(2M+N)$$

This index is less sensitive to differences in sample size than the Jaccard similarity index, because it normalizes with respect to the average number rather than the total number of species in the two samples. Since M is multiplied by a factor of two, this index places more weight on matches than on mismatches (Hammer and Harper, 2006).

3.2.2.3 Simpson's Coefficient of Similarity

Simpson's coefficient of similarity (Simpson, 1943), SCS, is calculated using:

$$SCS = M/S$$

S is the smaller of the number of taxa in each of the two samples. This index is insensitive to the size of the larger sample and also completely disregards absences in the smaller sample. Thus, this index may be appropriate in cases where sampling might be considered incomplete (Hammer and Harper, 2006).

3.2.2.4 Raup-Crick Similarity Index

The Raup-Crick similarity index (Raup and Crick, 1979), RCSI, can be viewed as a probability of equality. Based on any similarity index, the similarity of two samples can be statistically tested by using a randomization method (Hammer and Harper, 2006). The randomization procedure is as follows:

1. The two samples to be compared are pooled (all presences placed in one "bag"). Two random samples are then produced by pulling the same numbers of presences from the pool as the numbers of presences in the two original samples.
2. The above procedure is repeated 1000 times. The number of times that the similarity between a random pair of samples equals or exceeds the similarity between the original samples is then counted.
3. The number obtaining in step 2 is divided by the number of randomizations (1000),

giving an estimate of the probability p that the two original samples could have been taken from the same (pooled) population.

When the similarity index used in this randomization procedure equals the number of shared taxa (M), the probability p obtained is known as the Raup-Crick similarity index.

3.3 Temporal and Spatial Relationships of the Middle Devonian (the Givetian Age) Brachiopod Associations of Southwestern Ontario, and the Appalachian and Michigan Basins

To assess the temporal and spatial relationships (i.e., the evolutionary and palaeogeographical affinities) of the Middle Devonian (the Givetian age) brachiopod associations within southwestern Ontario, the Appalachian Basin, and the Michigan Basin, 38 brachiopod associations from Arkona-Thedford-Ipperwash area (southwestern Ontario), central and western New York (Appalachian Basin), and Thunder Bay region, Afton-Onaway region, Little Traverse Bay region of Michigan (Michigan Basin) (see Figure 3-1 and the Appendix A) were selected for multivariate analyses.

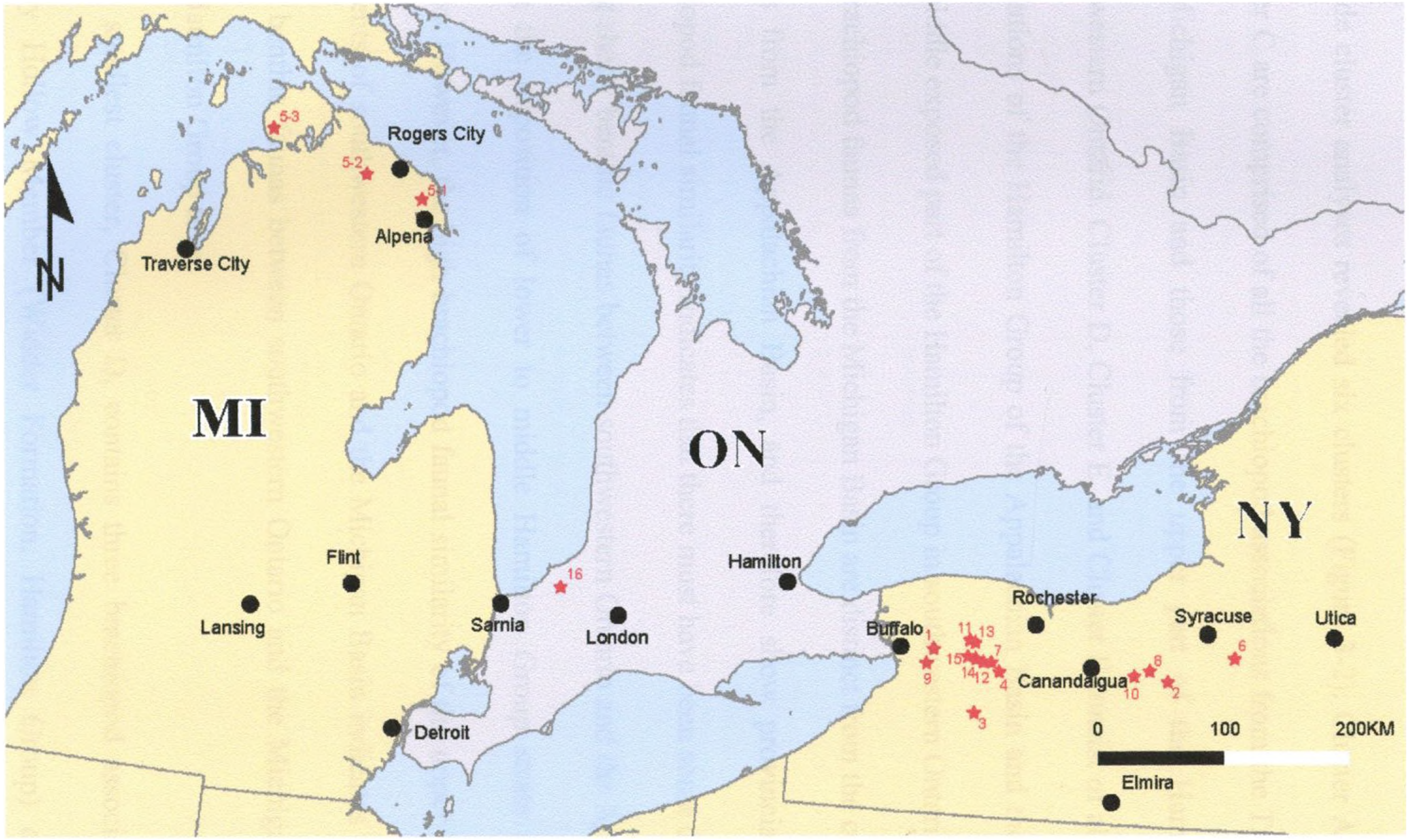


Fig. 3-1. Location map for the outcrop of the Middle Devonian Hamilton Group of southwestern Ontario and those of the equivalent strata of the Appalachian Basin and the Michigan Basin. Numbered sections refer to locations listed in Appendix A.

3.3.1 Cluster Analysis

3.3.1.1 Q-Mode Cluster Analyses & Similarity Measurements

Q-mode cluster analyses revealed six clusters (Figure 3-2). Cluster A, Cluster B, and Cluster C are comprised of all the brachiopod associations from the Traverse Group of the Michigan Basin and those from the upper part of the Hamilton Group of southwestern Ontario. Cluster D, Cluster E, and Cluster F consist of all the brachiopod associations of the Hamilton Group of the Appalachian Basin and those of the lower and middle exposed part of the Hamilton Group in southwestern Ontario. This indicates that brachiopod faunas from the Michigan Basin are distinct from the contemporaneous faunas from the Appalachian Basin, and therefore show provincialism. The high brachiopod faunal similarity indicates that there must have been some degree of mixing among shelly benthic faunas between southwestern Ontario and the Appalachian Basin during the deposition of lower to middle Hamilton Group strata in southwestern Ontario. However, the high brachiopod faunal similarity of the upper Hamilton Group sediments of southwestern Ontario and the Michigan Basin indicates some mixing of shelly benthic faunas between southwestern Ontario and the Michigan Basin during later Hamilton Group time.

The smallest cluster, Cluster D, contains three brachiopod associations from the Hungry Hollow Member (Widder Formation, Hamilton Group) of southwestern Ontario (ATIB), the Centerfield Member (Ludlowville Formation, Hamilton Group) of

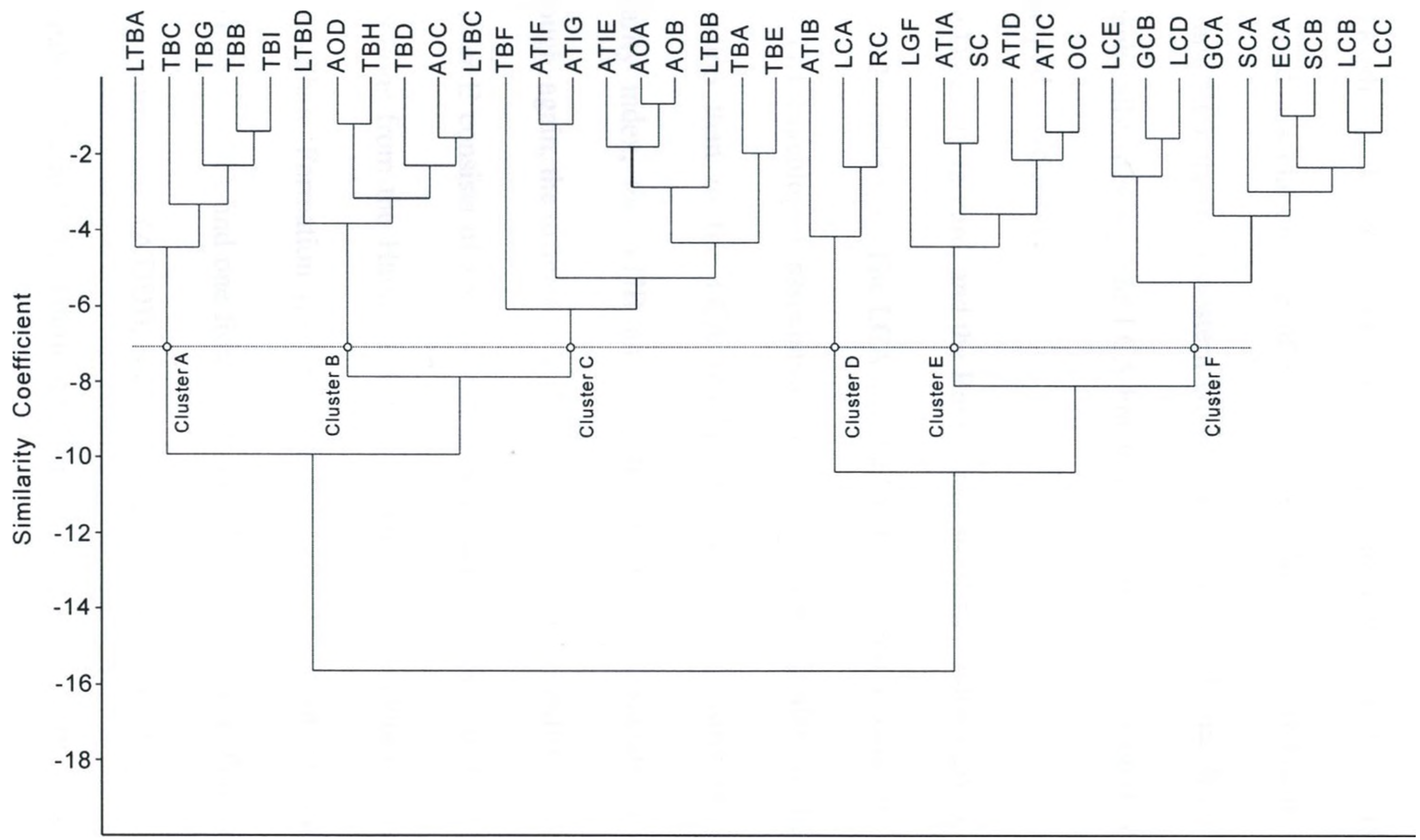


Fig. 3-2. Q-mode (taxa as variables) cluster analyses of 38 brachiopod associations from the Middle Devonian Hamilton Group of southwestern Ontario and the equivalent strata in the Appalachian Basin and the Michigan Basin, using the algorithm of Ward's method in the software package of PAST (Hammer and Harper, 2007) (See Appendix A for abbreviations of faunal occurrences).

western New York (Livingston County) (LCA), and the Darien Center Submember (the base of Wanakah Member, Ludlowville Formation, Hamilton Group) of western New York (Rush Creek) (RC). As it is indicated in Table 3-1, the ATIB and the LCA brachiopod associations are of similar age. The latter two brachiopod associations (LCA and RC) are from western New York and relatively much closer to each other geographically, although the LCA brachiopod association is slightly older than the RC brachiopod association.

The Dice, the Jaccard, and the Raup-Crick similarity indices give comparable results (Table 3-2, Table 3-3). The LCA and the RC brachiopod associations are most similar. The ATIB brachiopod association is slightly more similar to the RC brachiopod association than to the LCA brachiopod association. However, for the Simpson similarity index, the ATIB and the RC brachiopod associations are most similar (although, again, the difference in the similarity values is slight).

Cluster E consists of six brachiopod associations. These include: three brachiopod associations from the Hamilton Group of southwestern Ontario (one from the upper Arkona Shale Formation (ATIA), one from the Thedford Member of the Widder Formation (ATIC), and one from the Rock Glen Submember (Petrolia Member) of the Widder Formation (ATID)); one association from the Delphi Station Member (Skaneateles Formation, Hamilton Group) of central New York (OC); one association from the Ledyard Member (Ludlowville Formation, Hamilton Group) of western New

Michigan Basin	Southwestern Ontario			Appalachian Basin	
Thunder Bay Fm.	Sarnia Fm.			Moscow Fm.	Windom Mbr.
Potter Farm Fm.					
Norway Point Fm.	Ipperwash Limestone (Unnamed Fm.)				Portland Point / Kashong Mbr.
	Widder Formation	Petrolia Mbr.	Upper Petrolia Submbr.	Ludlowville Formation	Wanakah Mbr.
			Stony Point Submbr.		
Four-Mile Dam Fm.			Golden Creek Submbr.		
			Unnamed Submbr.		
			Rock Glen Submbr.		
		Thedford Mbr.			Ledyard Mbr.
		Hungry Hollow Mbr.			Centerfield Mbr.
Alpena Limestone	Arkona Shale Fm.			Skaneateles Fm.	Levanna Mbr.
Newton Creek Limestone					
Genshaw Fm.					
Ferron Point Fm.					Stafford Limestone
Rockport Quarry Limestone					
Bell Shale Fm.	Bell Shale Fm.			Marcellus Fm.	Cardiff Mbr.

Table 3-1. The correlation of the Middle Devonian Hamilton Group strata of southwestern Ontario with those contemporaneous strata of the Michigan Basin and the Appalachian Basin (After Bartholomew et al., 2006; Brett et al., 1991; Sanford, 1967)

York (SC); and one association from the Ledyard Member of central New York (LGF). Since the Delphi Station Member of the Skaneateles Formation (Hamilton Group) in New York is equivalent to the lower part of the Arkona Shale Formation (Hamilton Group) in southwestern Ontario (Bartholomew, et al., 2006), the ATIA fauna is relatively closer to the OC fauna in age (although slightly younger). As indicated in Table 3-1, the ATIC and ATID associations are similar to the SC and LGF associations in age.

In the Q-mode cluster analysis for Cluster E (Figure 3-2), the ATIC and the OC associations have the closest faunal similarity, although the latter association is older than the former one and they are separate geographically. The LGF association is the least similar to other associations of Cluster E. However, both the Dice and the Jaccard similarity indices (Table 3-4) show that the ATIC and the ATID associations which are from the same formation of the Hamilton Group in southwestern Ontario have the closest faunal similarity while the ATID and the SC associations is the least similar pairing. For the Simpson and the Raup-Crick similarity indices (Table 3-5), there is one or several maximally similar pairs (value 1.00), showing how the conservativeness of these two indices are paid for by a loss in sensitivity.

There are nine faunas from the Appalachian Basin in Cluster F (Figure 3-2). These include: four associations from the Hamilton Group in the Livingston County, New York (both the LCE and the LCC associations from the Kashong and Windom

	ATIB	LCA	RC
ATIB	—	0.42	0.44
LCA	0.59	—	0.56
RC	0.62	0.72	—

Table 3-2. Dice (lower triangle) and Jaccard (upper triangle) similarity indices between the faunas of Cluster D.

	ATIB	LCA	RC
ATIB	—	0.67	0.72
LCA	0.79	—	0.99
RC	0.80	0.74	—

Table 3-3. Simpson (lower triangle) and Raup-Crick (upper triangle) similarity indices between the faunas of Cluster D.

members of the Moscow Formation, the LCD association from the Ledyard and Wanakah members of the Ludlowville Formation, and the LCB association from the upper part of the Levanna Member of the Skaneateles Formation); two associations from the Hamilton Group in the Genesee County, New York (the GCB association from the Ledyard and Wanakah members of the Ludlowville Formation, and the GCA association from the Ledyard Member of the Ludlowville Formation); two associations from the Hamilton Group in the Seneca County, New York (the SCA association from the upper part of the Levanna Member of the Skaneateles Formation, and the SCB association from the middle part of the Windom Shale Member of the Moscow Formation); and one association from the Hamilton Group in the Erie County, New York (the ECA association from the lower part of the Ledyard Member of the Ludlowville Formation) (see Appendix A for details). The LCE association and the LCC association, the GCB association and the LCD association, and the SCA association and the LCB association are of the same age, respectively. The GCA association and the ECA association are also similar in age.

Cluster F is one of the two largest clusters and comprised of two subclusters (Figure 3-2). In the smaller subcluster, the GCB and the LCD associations are of similar age and have closer faunal similarity. In the bigger subcluster, the ECA association and the younger SCB association is the most similar pairing while the GCA association is the least similar to other associations.

Both the Dice and the Jaccard similarity indices (Table 3-6) show that the ECA and the SCB associations represent the most similar pairing while the SCA and the LCE associations the least similar. For the Simpson and the Raup-Crick similarity indices (Table 3-7), the SCA and the LCE associations is still the least similar pairing. However, since some same similarity values and several maximally similar pairs are present, these two indices are not desirable properties in the measurement of the faunal similarity within Cluster F.

Cluster A is the second smallest cluster (Figure 3-2). It includes: four associations from the Traverse Group in the Thunder Bay region of Michigan (the TBC association from the Genshaw Formation, the TBG association from the Norway Point Formation, the TBB association from the Ferron Point Formation, and the TBI association from the Thunder Bay Limestone); and one association from the Traverse Group in the Little Traverse Bay region of Michigan (the LTBA association from the Gravel Point Formation) (see Appendix A for the details). Their relative ages are indicated from Table 3-8. The TBI association is the youngest and the TBB association is the oldest within Cluster A.

In the Q-mode cluster analysis (Figure 3-2), the TBB and the TBI associations have the closest faunal similarity. The LTBA association from the Little Traverse Bay region is the least similar to the other four associations from the Thunder Bay region. The Dice and the Jaccard similarity indices (Table 3-9) also show that the TBB and the

	LGF	ATIA	SC	ATID	ATIC	OC
LGF	—	0.37	0.37	0.32	0.35	0.53
ATIA	0.54	—	0.57	0.50	0.46	0.58
SC	0.54	0.73	—	0.31	0.36	0.58
ATID	0.48	0.67	0.48	—	0.64	0.50
ATIC	0.52	0.63	0.53	0.78	—	0.60
OC	0.70	0.74	0.74	0.67	0.75	—

Table 3-4. Dice (lower triangle) and Jaccard (upper triangle) similarity indices between the faunas of Cluster E.

	LGF	ATIA	SC	ATID	ATIC	OC
LGF	—	0.93	0.92	0.86	0.97	1.00
ATIA	0.64	—	1.00	1.00	1.00	1.00
SC	0.64	0.73	—	0.86	0.95	1.00
ATID	0.60	0.70	0.50	—	1.00	1.00
ATIC	0.75	0.75	0.63	0.88	—	1.00
OC	1.00	0.88	0.88	0.75	0.75	—

Table 3-5. Simpson (lower triangle) and Raup-Crick (upper triangle) similarity indices between the faunas of Cluster E.

	LCE	GCB	LCD	GCA	SCA	ECA	SCB	LCB	LCC
LCE	—	0.38	0.30	0.23	0.08	0.14	0.23	0.13	0.15
GCB	0.56	—	0.55	0.33	0.38	0.54	0.43	0.40	0.36
LCD	0.46	0.71	—	0.25	0.30	0.36	0.36	0.33	0.40
GCA	0.38	0.50	0.40	—	0.33	0.50	0.50	0.46	0.42
SCA	0.14	0.56	0.46	0.50	—	0.60	0.45	0.55	0.36
ECA	0.25	0.70	0.53	0.67	0.75	—	0.80	0.73	0.55
SCB	0.38	0.60	0.53	0.67	0.63	0.89	—	0.73	0.55
LCB	0.24	0.57	0.50	0.63	0.71	0.84	0.84	—	0.64
LCC	0.27	0.53	0.57	0.59	0.53	0.71	0.71	0.78	—

Table 3-6. Dice (lower triangle) and Jaccard (upper triangle) similarity indices between the faunas of Cluster F.

	LCE	GCB	LCD	GCA	SCA	ECA	SCB	LCB	LCC
LCE	—	0.97	0.96	0.83	0.33	0.54	0.83	0.49	0.59
GCB	0.71	—	1.00	0.92	0.99	1.00	0.98	0.97	0.97
LCD	0.50	1.00	—	0.90	0.96	0.98	0.99	0.96	0.98
GCA	0.43	0.56	0.50	—	0.96	1.00	1.00	1.00	0.98
SCA	0.14	0.71	0.50	0.57	—	1.00	0.99	1.00	0.98
ECA	0.29	0.78	0.67	0.67	0.86	—	1.00	1.00	1.00
SCB	0.43	0.67	0.67	0.67	0.71	0.89	—	1.00	1.00
LCB	0.29	0.60	0.67	0.67	0.86	0.89	0.89	—	1.00
LCC	0.29	0.63	0.67	0.63	0.57	0.75	0.75	0.88	—

Table 3-7. Simpson (lower triangle) and Raup-Crick (upper triangle) similarity indices between the faunas of Cluster F.

TBI associations form the most similar pairing while the LTBA association is the least similar to the TBI association. For the Simpson and the Raup-Crick similarity indices (Table 3-10), although these two indices show that the LTBA association is the least similar to other associations, due to the presence of some same similarity values and several maximally similar pairs, these two indices also show how their conservativeness is paid for by a loss in sensitivity.

The six associations of Cluster B are also from the Traverse Group of the Michigan Basin. These include: two associations from the Little Traverse Bay region (the LTBC association from the Middle Petoskey Limestone, and the LTBD association from the Upper Petoskey Limestone); two associations from the Afton-Onaway region (the AOD association from the Beebe School Formation, and the AOC association from the Gravel Point Formation); and two associations from the Thunder Bay region (the TBH association from the Potter Farm Formation, and the TBD association from the Newton Creek Limestone). Since the Petoskey Limestone Formation is equivalent to the Potter Farm Formation (Table 3-8), the TBH association is similar to the LTBC and the LTBD associations in age. The Gravel Point Formation is equivalent to the Alpena Limestone Formation, thus, the AOC association is younger than the TBD association, and older than the TBH, the LTBC and the LTBD associations. For the AOD association, since the strata of the Beebe School Formation are equivalent to those of the Potter Farm Formation and the Thunder Bay Formation, the AOD association is younger than the

Northwestern Michigan (Little Traverse Bay region)	North Central Michigan (Afton-Onaway region)		Northeastern Michigan (Thunder Bay region)	
Whiskey Creek Fm.	Beebe School Fm.		Thunder Bay Fm.	
Petoskey Fm.			Potter Farm Fm.	
			Norway Point Fm.	
Charlevoix Fm.			Four-Mile Dam Fm.	
Gravel Point Fm.	Gravel Point Fm.		Alpena Limestone	Dock Street Clay Mbr.
				Lower Alpena Limestone
Koehler Fm.	Koehler Fm.		Newton Creek Limestone	
Genshaw Fm. (Undivided)	Genshaw Fm.	Upper Genshaw Fm.	Genshaw Fm.	Upper Genshaw Fm.
		Killians Mbr.		Killians Mbr.
		Lower Genshaw Fm.		Lower Genshaw Fm.
	Ferron Point Fm.		Ferron Point Fm.	
Rockport Quarry Limestone	Rockport Quarry Limestone		Rockport Quarry Limestone	
Bell Shale Fm.	Bell Shale Fm.		Bell Shale Fm.	

Table 3-8. Correlation of the Middle Devonian Traverse Group formations in the northern outcrop belt of the Michigan Basin. (After Ehlers and Kesling, 1970; Kesling et al., 1974; Wylie and Huntoon, 2003)

	LTBA	TBC	TBG	TBB	TBI
LTBA	—	0.42	0.52	0.36	0.27
TBC	0.59	—	0.48	0.61	0.42
TBG	0.69	0.65	—	0.60	0.57
TBB	0.53	0.76	0.75	—	0.67
TBI	0.43	0.59	0.73	0.80	—

Table 3-9. Dice (lower triangle) and Jaccard (upper triangle) similarity indices between the faunas of Cluster A.

	LTBA	TBC	TBG	TBB	TBI
LTBA	—	0.87	1.00	0.93	0.80
TBC	0.61	—	0.98	1.00	1.00
TBG	0.85	0.77	—	1.00	1.00
TBB	0.73	1.00	0.82	—	1.00
TBI	0.67	0.89	0.89	0.89	—

Table 3-10. Simpson (lower triangle) and Raup-Crick (upper triangle) similarity indices between the faunas of Cluster A.

TBD and the AOC associations but similar to the LTBD, the TBH, and the LTBC associations in age.

The AOD and the TBH associations form the most similar pairing in the Q-mode cluster analysis (Figure 3-2). The LTBD association is the least similar to other associations of Cluster B. The Dice and the Jaccard similarity indices show the same results (Table 3-11). For the Simpson and the Raup-Crick similarity indices (Table 3-12), several maximally similar pairs show up, which indicates that these two indices are not desirable properties for this case.

The other of the two largest cluster is Cluster C, comprised of nine associations, too. The nine associations include: three associations from the Hamilton Group of southwestern Ontario (the ATIE association from the Golden Creek Submember of the Petrolia Member (Widder Formation), the ATIF association from the Stony Point Submember of the Petrolia Member, and the ATIG association from the Ipperwash Limestone (unnamed formation)); three associations from the Traverse Group of the Thunder Bay region (the TBA association from the Bell Shale Formation, the TBE association from the Alpena Limestone, and the TBF association from the Four Mile Dam Formation); two associations from the Traverse Group of the Afton-Onaway region (the AOA association from the Ferron Point Formation, and the AOB association from the Genshaw Formation), and one association from the Charlevoix Limestone of the Traverse Group within the Little Traverse Bay region (the LTBB

	LTBD	AOD	TBH	TBD	AOC	LTBC
LTBD	—	0	0	0.13	0.10	0
AOD	0	—	0.40	0.13	0.22	0
TBH	0	0.57	—	0.20	0.33	0
TBD	0.22	0.22	0.33	—	0.25	0
AOC	0.18	0.36	0.50	0.40	—	0.17
LTBC	0	0	0	0	0.29	—

Table 3-11. Dice (lower triangle) and Jaccard (upper triangle) similarity indices between the faunas of Cluster B.

	LTBD	AOD	TBH	TBD	AOC	LTBC
LTBD	—	0.21	0.33	0.67	0.53	0.45
AOD	0	—	0.99	0.66	0.88	0.42
TBH	0	1.00	—	0.86	0.99	0.47
TBD	0.25	0.25	0.50	—	0.91	0.44
AOC	0.20	0.40	1.00	0.50	—	0.88
LTBC	0	0	0	0	1.00	—

Table 3-12. Simpson (lower triangle) and Raup-Crick (upper triangle) similarity indices between the faunas of Cluster B.

association). Based on correlations of the formations shown in Table 3-1 and Table 3-8, the relative age of the nine associations should be as follows (from old to young): the TBA association, the AOA association, the AOB association, the TBE association, the TBF association/the LTBB association (both are of similar age), the ATIE association, the ATIF association, and the ATIG association.

In the Q-mode cluster analysis of Cluster C (Figure 3-2), the two associations (AOA, AOB) from the Afton-Onaway region form the most similar pairing. The two associations (ATIF, ATIG) from southwestern Ontario form the second most similar pairing. These two features also can be indicated by the Dice and the Jaccard similarity indices (Table 3-13). Besides these two features, these two indices show that the AOA and the ATIG associations is the least similar pairing. For the Simpson and the Raup-Crick similarity indices (Table 3-14), the results are not desirable, due to the presence of several maximally similar pairs (value 1.00).

3.3.1.2 R-Mode Cluster Analyses

The R-mode cluster analysis (Figure 3-3) indicates that some taxic clusters have a relatively high degree of correspondence to a certain geological area. For instance, the relatively small cluster of 3-4-15-37-53-56 (see Appendix B for generic names) only shows up in the Little Traverse Bay region (i.e., in LTBA and LTBB associations) and the Thunder Bay region (i.e., in the TBB, TBC, and TBG associations) of Michigan

	TBF	ATIF	ATIG	ATIE	AOA	AOB	LTBB	TBA	TBE
TBF	—	0.25	0.21	0.19	0.14	0.13	0.25	0.16	0.16
ATIF	0.40	—	0.70	0.44	0.11	0.22	0.27	0.23	0.33
ATIG	0.35	0.82	—	0.45	0.08	0.17	0.38	0.27	0.36
ATIE	0.32	0.62	0.63	—	0.29	0.43	0.50	0.36	0.36
AOA	0.25	0.20	0.15	0.44	—	0.75	0.25	0.20	0.09
AOB	0.24	0.36	0.29	0.60	0.86	—	0.33	0.18	0.18
LTBB	0.40	0.42	0.55	0.67	0.40	0.50	—	0.31	0.31
TBA	0.27	0.38	0.42	0.53	0.33	0.31	0.48	—	0.38
TBE	0.27	0.50	0.53	0.53	0.17	0.31	0.48	0.56	—

Table 3-13. Dice (lower triangle) and Jaccard (upper triangle) similarity indices between the faunas of Cluster C.

	TBF	ATIF	ATIG	ATIE	AOA	AOB	LTBB	TBA	TBE
TBF	—	0.84	0.49	0.70	0.79	0.64	0.62	0.40	0.38
ATIF	0.57	—	1.00	1.00	0.65	0.87	0.90	0.78	0.93
ATIG	0.40	1.00	—	1.00	0.57	0.80	0.95	0.84	0.94
ATIE	0.50	0.67	0.83	—	0.96	0.99	1.00	0.99	0.97
AOA	0.67	0.33	0.33	0.67	—	1.00	0.98	0.88	0.57
AOB	0.50	0.50	0.50	0.75	1.00	—	0.99	0.81	0.83
LTBB	0.42	0.57	0.60	1.00	1.00	1.00	—	0.91	0.88
TBA	0.33	0.43	0.44	0.67	0.67	0.50	0.56	—	0.97
TBE	0.33	0.57	0.56	0.67	0.33	0.50	0.56	0.56	—

Table 3-14. Simpson (lower triangle) and Raup-Crick (upper triangle) similarity indices between the faunas of Cluster C.

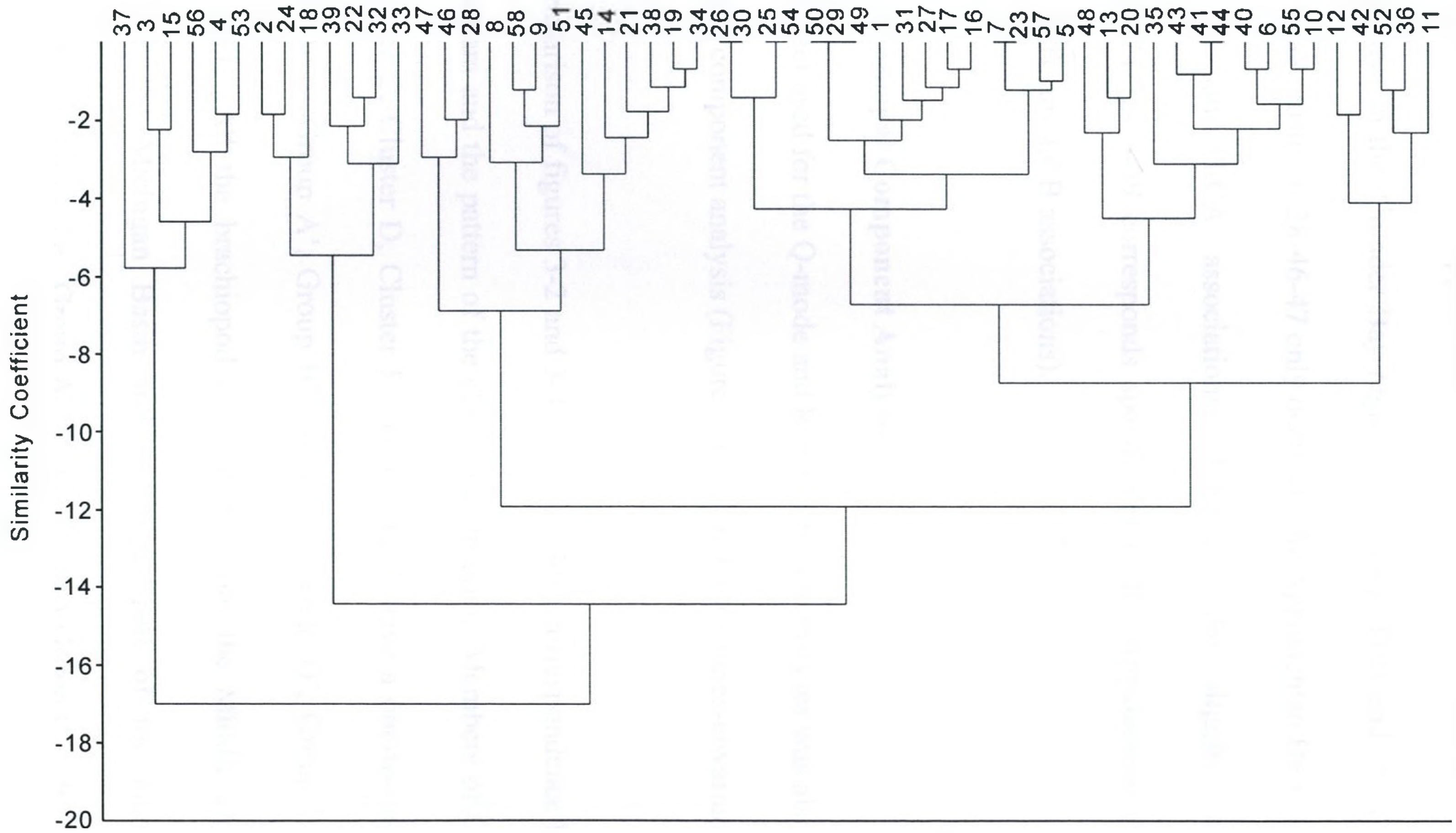


Fig. 3-3. R-mode (ages/localities as variables) cluster analyses of 38 brachiopod associations from the Middle Devonian Hamilton Group of southwestern Ontario and the equivalent strata in the Appalachian Basin and the Michigan Basin, using the algorithm of Ward's method in the software package of PAST (Hammer and Harper, 2007) (See Appendix B for number codes).

(the Michigan Basin) and southwestern Ontario (i.e., in the ATIB and the ATIG associations), not in the Appalachian Basin. Another small cluster of 11-12-36-42-52 is only present in the Thunder Bay region (i.e., in the TBB and the TBC associations), and a small cluster of 28-46-47 only occurs in the Appalachian Basin (i.e., in the LGF, SC, OC, and LCA associations). Likewise, the slightly larger cluster of 2-18-22-24-32-33-39 corresponds specifically to the Appalachian Basin (i.e., in the ECA, SCB, and LCB associations).

3.3.2 Principal Component Analysis

The dataset used for the Q-mode and R-mode cluster analyses was also subjected to a principal component analysis (Figure 3-4), using the variance-covariance algorithm of PAST.

Comparison of figures 3-2 and 3-4 reveals a close correspondence between the PCA scattergram and the pattern of the cluster dendrogram. Members of Cluster A, Cluster B, Cluster C, Cluster D, Cluster E, and Cluster F have a one-to-one correspondence with those of Group A', Group B', Group C', Group D', Group E', and Group F', respectively. All the brachiopod associations from the Middle Devonian Traverse Group of the Michigan Basin and the upper part of the Hamilton Group of southwestern Ontario (i.e., Group A', Group B', and Group C') show gathering at the lower left portion of the scattergram. All the brachiopod associations from the Middle

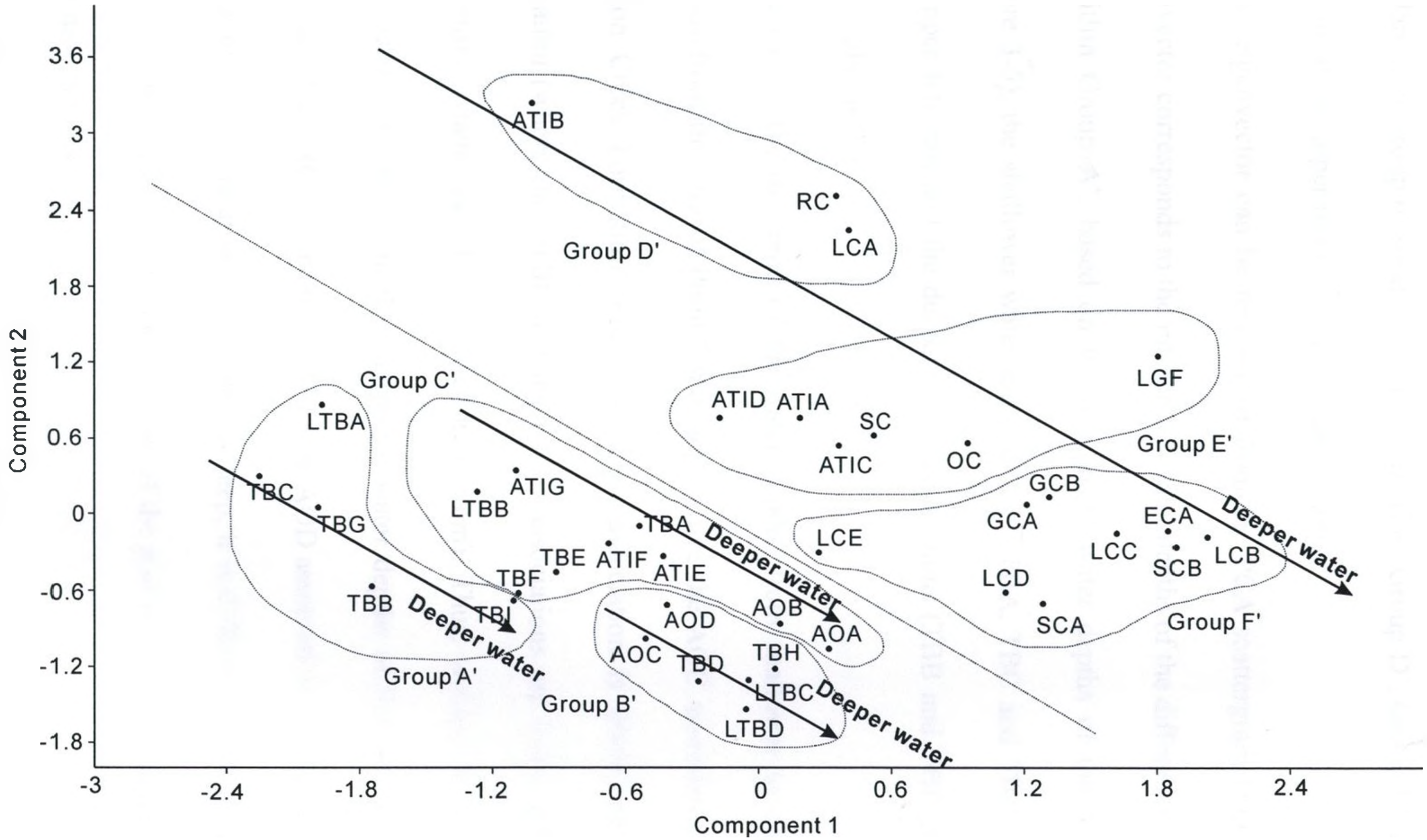


Fig. 3-4. Principal component analysis (PCA) of 38 brachiopod associations from the Middle Devonian Hamilton Group of southwestern Ontario and the equivalent strata in the Appalachian Basin and the Michigan Basin (See Appendix A for the abbreviations of faunal occurrences).

Devonian Hamilton Group of the Appalachian Basin and the relatively lower part of the Hamilton Group of southwestern Ontario (i.e., Group D', Group E', and Group F') show up at the upper right part of the scattergram.

One eigenvector can be recognized from the PCA scattergram (Figure 3-4). This eigenvector corresponds to the interpreted water depths of the different associations.

Within Group A', based on the interpreted water depths of the Michigan Basin (Figure 3-5), the shallower water associations (LTBA, TBC and TBG) are present at the upper left part and the deeper water associations (TBB and TBI) show up at the lower right portion.

For Group B', the trend of the water depths, from shallower to deeper, is quite obvious from the Gravel Point Formation (where the AOC association is from), the Newton Creek Formation (where the TBD association is from), to the Petoskey Formation (where the LTBC and the LTBD associations are from) and Potter Farm Formation (where the TBH association is from). Thus, within Group B', the same eigenvector corresponds to the interpreted water depths of the associations, with the exception of the AOD association. Since the AOD association is from the Beebe School Formation and the relative water depth is deep, it is difficult to explain why the AOD association is located at the upper left part of the plot otherwise occupied by shallower water associations.

As indicated in Figure 3-4, the same eigenvector corresponds to the interpreted water

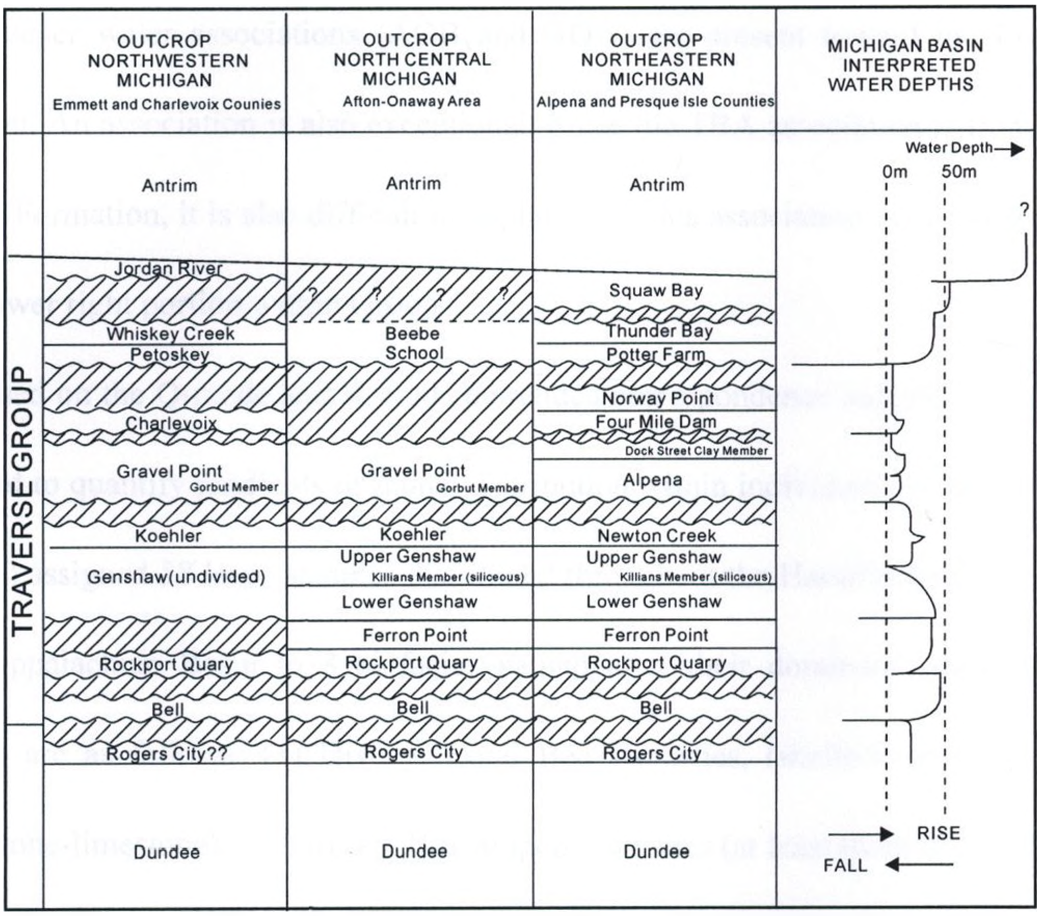


Fig. 3-5 The water-depth curve for the Middle Devonian Traverse Group of Michigan Basin, based on published outcrop and subsurface stratigraphic descriptions and the results of application of the log-curve amplitude-slicing method to gamma-ray log data (After Wylie and Huntoon, 2003).

depths of the associations within Group C'. The shallower water associations (ATIG, LTBB, TBF, TBE, ATIF, ATIE) are grouped together towards the upper left part and the deeper water associations (AOB and AOA) are present toward the lower right portion. An association is also exceptional. Since the TBA association is from the Bell Shale Formation, it is also difficult to explain why this association does not show up at the lower right portion within Group C'.

Based on the Q-mode and R-mode detrended correspondence analysis (DCA, which is used to quantify gradients of faunal distribution within individual cycles), Brett et al. (2007) assigned 58 large samples distributed throughout the Hamilton-Tully interval of the Appalachian Basin to 8 biofacies named after their dominant constituent taxa. These are as follows: (1) Diverse Coral Bed Biofacies, (shallow water, calcareous mudstone-limestone), (2) Diverse Brachiopod Biofacies (at least three species of larger strophomenid or atrypid brachiopods, shallow shelf, calcareous mudstone), (3) *Tropidoleptus carinatus-Nucleospira concinna* (shallow shelf, turbid water, silty mudstone), (4) *Stereolasma rectum-Eldredgeops rana* (midshelf, oxic gray calcareous mudstone), (5) *Athyris* sp.-*Mediospirifer audaculus* (midshelf, oxic gray mudstone), (6) *Ambocoelia umbonata* and small chonetids (deep-shelf, dysoxic-oxic gray mudstone), (7) *Arcuaminetes scitulus* (deep-shelf, dysoxic-oxic gray mudstone), (8) *Eumetabolotoechia multicostum* (deep-basin, dysoxic black shale).

Group D' consists of three brachiopod associations (ATIB, RC, and LCA). The

ATIB association from the Hungry Hollow Member (Widder Formation) and the LCA association from the Centerfield Member (Ludlowville Formation) are included. These two members are of similar age and both contain abundant large rugose and tabulate corals, indicating a shallow water environment (Brett et al., 2007), The RC association is from basal limestone beds of the Wanakah Member (Ludlowville Formation) and it has a very close faunal similarity to the LCA and ATIB associations. All these attributes suggest strongly this association represents a shallow water environment.

All the associations of Group E' (ATIA, ATIC, ATID, SC, OC, and LGF) are from shale/mudstone-dominated stratal units indicative of a deeper water environment than that recorded by Group D'. Based on the faunal gradients in the Middle Devonian (Brett et al., 2007), the *Stereolasma rectum-Eldredgeops rana* biofacies and the *Mucrospirifer-Chonetid* (note: some species mistakenly assigned to *Chonetes* have been assigned to *Devonochonetes*) biofacies share the same water depth. The shift of the former biofacies to the latter one indicates increased turbidity. Due to the presence of abundant *Mucrospirifer* and *Devonochonetes*, the ATIA association should belong to biofacies 4 (midshelf, oxic gray calcareous mudstone). Since the ATIA association has a high faunal similarity to the ATIC and ATID associations and the latter two associations are also from oxic gray calcareous mudstone, these three associations should be assigned to the same biofacies. Since the Delphi Station Member (Skaneateles Formation) consists of barren dark-gray mudstone with scattered pyritic burrows (Bartholomew, et al., 2006), the OC association should belong to biofacies 6 (deep-shelf, dysoxic-oxic gray mudstone). Both the SC association and the LGF association are from the Ledyard Member (Ludlowville Formation), which consists of gray mudstone with some nodular pyrite, thus, these two associations should also be assigned to biofacies 6.

For Group F', the ECA, the SCB, the LCB, and the SCA associations are from black shale beds and *Eumetabolotoechia* shows up in each of them. Thus, they should belong to biofacies 8, the *Eumetabolotoechia multicostum* biofacies (deep-basin, dysoxic black shale). The remaining five associations (LCE, GCA, GCB, LCC, and LCD) come from gray mudstone beds with some nodular pyrite, which indicates these five associations should be assigned to biofacies 6.

Thus, the same eigenvector corresponds to the interpreted water depths of the different associations from the Middle Devonian Hamilton Group of the Appalachian Basin and the relatively lower part of the Hamilton Group of southwestern Ontario.

3.4 Discussion

As the Q-mode cluster analysis (Figure 3-2) indicates, there must have been a common mixing of benthic shelly faunas between southwestern Ontario and the Appalachian Basin during deposition of the lower to middle Hamilton strata of southwestern Ontario while some mixing of shallow water benthic shelly faunas appears to have occurred between southwestern Ontario and the Michigan Basin in the deposition of the upper Hamilton strata of the study area. The Middle Devonian tectonic events of eastern North America provide some possibilities how these faunal patterns may have been achieved.

Based on the high-resolution correlation of the Middle Devonian Hamilton Group equivalent strata in terms of sequence stratigraphy in east-central North America (Ontario, Canada, as well as New York, southern Michigan, northern Ohio and Indiana, USA), Bartholomew and Brett (2007) deduced a north-northeastward facies trend oriented perpendicular to an east-dipping ramp from the present day western Ohio-Indiana line through eastern Ohio into New York. According to them, during deposition of the upper Skaneateles and lower Ludlowville sediments, the Findlay Arch had not yet come into being. This suggests that, unlike today, in which the Findlay Arch physically separates the Appalachian Foreland Basin from the Michigan Intracratonic Basin, there was no barrier between these two basins when lower to middle Hamilton strata were being deposited (Bartholomew and Brett, 2007). Significantly, the Q-mode cluster analysis of brachiopod associations in the present study indicates that in spite of the proximity of the area of the present study to the Michigan Basin, the brachiopod associations of southwestern Ontario freely interchanged with those of the Appalachian Basin during the deposition of the lower to middle Hamilton Group strata.

Obvious condensation from the upper Ludlowville Formation through the whole

Moscow Formation in Ohio (the Sandusky area) suggests gentle upwarping of this area during later Givetian time, which probably caused the truncation of most of the previous deposited Hamilton sediments located to the east (between Sandusky and the Appalachian Basin). Such a paleotopographic high, possibly representing a forebulge that developed in response to renewed thrust loading during the third tectophase of the Acadian Orogeny (Ettensohn, 1987) may well have been a precursor of the Findlay Arch (Bartholomew and Brett, 2007).

Although the major Algonquin-Findlay Arch, which presently separates the Michigan Basin from the Appalachian Basin, is thought not to have been present during deposition of the Hamilton Group sediments, upper Hamilton Group strata appear to have been deposited as condensed beds in a roughly north-south trending belt in the vicinity of present-day Cleveland, Ohio, suggesting that this area underwent topographic inversion, possibly producing a local arch (Bartholomew and Brett, 2007). This, in turn, suggests that, by this time, the two basins were not as well connected as they were previously, and could explain why southwestern Ontario was faunally more closely associated with the Michigan Basin during the deposition of the upper Hamilton strata.

Yet another possibility for the shift in the affinities of the southwestern Ontario brachiopod associations from those of Appalachian Basin-type to those of Michigan Basin-type is that a structural arch did exist between the two basins but that lithologic evidence for such a feature has simply not yet been noticed. If the former existence of such a feature (perhaps as a forebulge that passed eastward under the study area just before the upper Hamilton Group strata were deposited), were to be recognized, it would explain not only the above-described shift in faunal affinities observed in Ontario, but would also account for why the faunas of the two basins remained distinct (even during the deposition of the lower Hamilton Group strata when immigration of the Appalachian fauna into southwestern Ontario was taking place). Future sedimentologic/lithostratigraphic studies will be required to assess the validity of this alternative hypothesis.

3.5 Conclusions

Multivariate analyses of the 38 brachiopod associations from the Hamilton Group of southwestern Ontario and the equivalent strata in the Appalachian and the Michigan basins have revealed the following points:

1) Middle Devonian (Givetian age) brachiopod faunas from the Michigan Basin are distinct from contemporaneous faunas from the Appalachian Basin, allowing identification of separate Michigan Basin and Appalachian Basin faunal subprovinces.

2) In spite of the present-day location of southwestern Ontario at the southeastern edge of the Michigan Basin, the brachiopod associations of southwestern Ontario were

more similar to those in contemporaneous strata of the Appalachian Basin when lower to middle Hamilton strata were being deposited. This was due to the probable lack of a topographic high in the present-day Findlay Arch area that would have otherwise prevented immigration of Appalachian Basin fauna into the study area. Alternatively, there remains the possibility that an arch feature did exist between southwestern Ontario and the Michigan Basin despite the fact that lithologic indicators have, thus far, suggested otherwise.

3) Due to the formation of a local arch at present-day Cleveland area of Ohio, during the deposition of the upper Hamilton strata, the immigration of Appalachian Basin taxa into the study area was impeded, leading to a closer similarity of brachiopod associations of southwestern Ontario to those of the Michigan Basin.

Chapter 4: Summary and Conclusions

4.1 Summary and Conclusions of Results

Based on the preceding results and discussions, the following summary and conclusions may be drawn:

1. Recent work by Bartholomew et al. (2006) on the stratigraphy of the Middle Devonian Hamilton Group has led to the redefinition of stratal units within this succession in southwestern Ontario. Changes made to the lithostratigraphic framework include the following:

   a) The Bell Shale Formation includes the limestone beds previously included in the Dundee Formation.

   b) The former Rockport Quarry Formation is now included in the basal part of the Arkona Shale Formation.

   c) The former Hungry Hollow Formation is now considered the basal member of the Widder Formation and its units 1-5 in the previous work have been assigned to the underlying Arkona Shale Formation.

   d) The Stony Point Submember of Petrolia Member (Widder Formation) and the Ipperwash Limestone (unnamed formation) are equivalent to “the Lower Ipperwash Limestone” and “the Upper Ipperwash Limestone”of Wright and Wright (1963), respectively.

   e) A new formation, Sarnia Formation, is defined named by Bartholomew et al.

(2006), is only preserved in subsurface near Sania, Ontario, Canada.

Based on her own examination of Hamilton Group strata of southwestern Ontario in outcrop and drillcores stored at the Oil, Gas & Salt Resources Library, London, Ontario, the present author agrees with the revised scheme and has cited within this thesis, brachiopod occurrences recorded by both her and previous authors, in context of this new framework. This will provide a foundation on which the biostratigraphy of other faunal groups in the succession can be based.

2. The brachiopod collection derived from the exposed strata of the Hamilton Group of southwestern Ontario comprises 50 species assigned to 34 genera, among which *Devonochonetes arkonensis* n. sp. is a new species. All the species formerly assigned to the genus *Mucrospirifer* actually belong to a single polytypic species: *Mucrospirifer mucronatus* (Conrad, 1841) (Welch, 1991).
3. Seven brachiopod associations have been recognized in the exposed strata of the Hamilton Group of southwestern Ontario:

   a) The brachiopod association represented in the exposed upper part of the Arkona Shale Formation, includes 11 species assigned to 8 genera, among which *Mucrospirifer mucronatus* (Conrad, 1841) and *Devonochonetes arkonensis* n. sp. are two dominant brachiopod species. Additional brachiopod taxa include *Strophodonta* (*Strophodonta*) *demissa* (Conrad, 1842), *S. extenuata ferronensis* Imbrie, 1955, *S.* cf. *fascis* Imbrie, 1959, *Devonochonetes coronatus* (Conrad, 1842), *Productella truncata* (Hall, 1857), *Devonalosia wrightorum* Muir-Wood & Cooper, 1960, *Floweria arctostriata* (Hall, 1843), *Spinocyrtia mourantae* Ehlers& Wright, 1955, and *Cyrtina arkonensis* Ehlers & Wright, 1975.

b) The brachiopod association represented in the Hungry Hollow Member of the Widder Formation, contains 37 species assigned to 32 genera. These species are as follows: *Lingula*? *thedfordensis* Whiteaves, 1889, *Orbiculoidea doria* (Hall, 1863), *Petrocrania hamiltoniae* (Hall, 1860), *Philhedra crenistriata* (Hall, 1860), *Douvillina* cf. *inaequistriata* (Conrad, 1842), *Protoleptostrophia perplana*, *Strophodonta* (*Strophodonta*) *demissa* (Conrad, 1842), *Strophodonta* sp., *Strophodonta titan titan* Imbrie, 1959 ?, *Megastrophia concava*, *Pholidostrophia nacrea*, *Devonochonetes coronatus*, *Floweria* sp., *Rhipidomella vanuxemi*, *Rhipidomella penelope*, *Pentamerella* cf. *pavilionensis* (Hall, 1860), *Callipleura nobilis* (Hall, 1860), *Camarotoechia thedfordensis*, *Leiorhynchus laura* (Billings, 1860), *Stenoscisma kernahani* (Whiteaves, 1898), *Spinocyrtia granulosa* (Conrad, 1839), *Atrypa* (*Atrypa*) *reticularis*, *Pseudoatrypa* cf. *devoniana* (Webster, 1921), *Athyris spiriferoides*, *Athyris vittata*, *Charionella scitula* (Hall, 1843), *Pentagonia bisulcata* (Cooper)?, *Nucleospira concinna*, *Parazyga* cf. *hirsuta* (Hall, 1857), ?*Mediospirifer* sp., *Ambocoelia tuberculata*, *Mucrospirifer mucronatus*, *Elita fimbriata* (Conrad, 1842), *Cyrtina coultisorum* Ehlers & Wright, 1975, *Cranaena romingeri*, *Cranaena harmonia* (Hall, 1867), and *Cryptonella attenuata*

(Whiteaves, 1898).

c) The brachiopod association of the Thedford Member (Widder Formation) includes 9 species assigned to 8 genera, among which are *Protoleptostrophia perplana*, *Pholidostrophia nacrea*, *Devonochonetes arkonensis* n. sp., *Leiorhynchus laura*, *Athyris vittata*, *Athyris spiriferoides*, *Ambocoelia tuberculata*, *Cyrtina angularis*, and very abundant *Mucrospirifer mucronatus*.

d) The brachiopod association of the Rock Glen Submember of the Petrolia Member (Widder Formation) is comprised of 11 species belonging to 10 genera, including *Protoleptostrophia perplana*, *Strophodonta* (*Strophodonta*) *demissa*, *Megastrophia concava*, *Pholidostrophia nacrea*, *Devonochonetes arkonensis* n. sp, *Floweria arctostriata*, *Leiorhynchus laura*, *Athyris spiriferoides*, *Athyris vittata*, *Cyrtina angularis*, and abundant *Mucrospirifer mucronatus*.

e) The brachiopod association of the Golden Creek Submember of the Petrolia Member (Widder Formation) consists of 6 species belonging to 6 genera. These taxa include: *Devonochonetes arkonensis* n. sp., *Atrypa* (*Atrypa*) *reticularis*, *Athyris spiriferoides*, *Spinocyrtia parvigranulata* Ehlers & Wright, 1955, *Cyrtina angularis*, and abundant *Mucrospirifer mucronatus*.

f) The brachiopod association of the Stony Point submember of the Petrolia Member (Widder Formation) is comprised by 8 species assigned to 7 genera, including *Protoleptostrophia perplana; Megastrophia concava; Rhipidomella* *penelope; Atrypa* (*Atrypa*) *reticularis; Spinocyrtia ravenswoodensis* Ehlers & Wright, 1955; *Spinocyrtia granulosa; Cyrtina staufferi;* and *Mucrospirifer mucronatus*.

g) The brachiopod association of Ipperwash Limestone (unnamed formation) consists of 13 species assigned to 10 genera. They are: *Protoleptostrophia perplana*, *Strophodonta* (*Strophodonta*) *demissa*, *Megastrophia concava*, *Rhipidomella vanuxemi*, *Rhipidomella penelope*, *Atrypa* (*Atrypa*) *reticularis*, *Pseudoatrypa* cf. *devoniana*, *Athyris spiriferoides*, *Athyris vittata*, *Spinocyrtia ravenswoodensis*, *Spinocyrtia granulosa*, *Cyrtina staufferi*, and *Mucrospirifer mucronatus*.

4. Conclusions that may be drawn from the multivariate analyses of the 38 brachiopod associations from the Hamilton Group of southwestern Ontario and the equivalent strata in the Appalachian and the Michigan basins are as follows:

a) Middle Devonian (Givetian age) brachiopod faunas from the Michigan Basin and those from contemporaneous faunas of the Appalachian Basin are distinct, allowing identification of separate Michigan Basin and Appalachian Basin faunal subprovinces.

b) In spite of its proximity to the Michigan Basin (presently at the southeastern edge of the Michigan Basin), southwestern Ontario had brachiopod associations that more closely resembled those in contemporaneous strata of the Appalachian

Basin during the deposition of the lower and middle Hamilton Group sediments. This may have been due to the lack of a topographic high in the present-day Findlay Arch area that would have otherwise prevented immigration of Appalachian Basin fauna into the study area. Alternatively, there remains the possibility that an arch feature did exist between southwestern Ontario and the Michigan Basin despite the fact that lithologic indicators have, thus far, suggested otherwise.

c) During the deposition of the upper Hamilton strata, immigration of brachiopod faunas from the Appalachian Basin into the study area was impeded, leading to a closer similarity of brachiopod associations of southwestern Ontario to those of the Michigan Basin. This change in faunal affinity may have been related to the formation of a local arch at present-day Cleveland area of Ohio that blocked the immigration of Appalachian Basin taxa into the study area.

4.2 Future Work

There are a number of observations made in the present study that, although could not be pursued by the author due to time constraints, demand further investigation. Suggestions for future work on the Hamilton Group of southwestern Ontario include the following:

a) Brachiopods are but one group of organisms that occurs in abundance in the studied succession. Future studies on other faunal components of the Hamilton Group of southwestern Ontario, particularly corals, bivalves and cephalopods will be required to further refine the biostratigraphy of the succession as a whole.

b) As the shells of brachiopods such as *Mucrospirifer* and *Devonochonetes* occur more or less throughout the Hamilton Group succession, these genera would be ideal for taphonomic comparisons among strata of various units. In particular, comparisons of disarticulation rates, degrees of fragmentation and abrasion, and shell orientation, may serve to refine changes in depositional controls such as water depth that would aid in interpretations of paleoenvironmental change within the succession.

c) The present study has indicated continuous morphological variation in *Mucrospirifer mucronatus*, a taxon previously assigned to multiple species. Future work is needed to investigate the paleoenvironmental factors, such as substrate consistency, that may have affected this variation. Such work will require the study of *in situ* specimens in context of sedimentary features preserved in their entombing sediments.

d) In this study, the comparison of brachiopod associations in southwestern Ontario and those of the Michigan and Appalachian basins suggests that, despite claim of Bartholomew and Brett (2007) that no physical barrier apart from a minor uplift in the Cleveland area of Ohio existed between the two basins, there was a clear separation in the affinities of their respective brachiopod faunas. Moreover, the observation that the southern Ontario associations show a closer affinity to the

Michigan Basin fauna in the upper Hamilton beds than in the lower strata raises the possibility that lithological evidence of a physical barrier to migration exists in the Hamilton Group strata of the study area but has simply escaped notice. High-resolution stratigraphic work will clearly be required to investigate this possibility further.

References

Ahern, J. L., and Dikeou, P. J. 1989. Evolution of the lithosphere beneath the Michigan Basin. Earth and Planetary Science Letters, 95:73-84.

Alexander, F. E. S. 1949. Revision of the brachiopod species *Anomia reticularis* Linnaeus, genolectotype of *Atrypa* Dalman. Quarterly Journal of the Geological Society, London, 104: 207-220.

Alvarez, F., Rong, J., and Boucot, A. J. 1998. The classification of athyridid brachiopods. Journal of Paleontology, 72(5): 827–855.

Baranov, V. V., and Alkhovik, T. S. 2006. Brachiopods of the Family Ambocoeliidae (Spiriferida) from the Givetian of Southern Verkhoyansk Region (Northeastern Russia). Paleontological Journal, 40(2): 162-167, 1 pl..

Bartholomew, A. J. 2006. Middle Devonian Faunas of the Michigan and Appalachian Basins: Comparing Patterns of Biotic Stability and Turnover between two Paleobiogeographic Subprovinces. Ph.D. Dissertation. Department of Geology, University of Cincinnati. 288pp.

Bartholomew, A. J., and Brett, C. E. 2007. Correlation of Middle Devonian Hamilton Group-equivalent strata in east-central North America: implications for eustasy, tectonics, and faunal provinciality. In: R. T., Becker (ed.), Devonian events and correlations. Geological Society Special Publication, 278: 105-131.

Bartholomew, A. J., Brett, C. E., DeSantis, M., Baird, G. C. and Tsujita, C. J. 2006. Sequence stratigraphy of the Middle Devonian at the border of the Michigan Basin: Correlations with New York and Implications for sea-level change and paleogeography. Northeastern Geology and Environmental Sciences, 28:2-33.

Baumiller, T. K. 2002. Multi–snail infestation of Devonian crinoids and the nature of platyceratid–crinoid interactions. Acta Palaeontologica Polonica, 47 (1): 133–139.

Becker, T. P., Thomas, W. A., Samson, S. D., and Gehrels, G. E. 2005. Detrital zircon evidence of Laurentian crustal dominance in the lower Pennsylvanian deposits of the Alleghanian clastic wedge in eastern North America. Sedimentary Geology, 182: 59-86.

Beecher, C. E. 1891. Development of the Brachiopoda. Part 1. Introduction. American Journal of Science, Ser.3, 41: 343-357, 1 pl..

Billings, E. 1857. Fossils of the Hamilton Group. Canadian Naturalist and Geologist, 1(4): 471-479.

Billings, E. 1860. On the Devonian fossils of Canada West. Canadian Journal of Science, Literature, and History, N. S., 5: 249-282.

Billings, E. 1861. Note on a new genus of Paleozoic Brachiopoda. Canadian Journal of Industry, Science and Art, 6: 148.

Billings, E. 1874. Palaeozoic Fossils, vol. 2, Part 1. Canadian Geological Survey. Montreal: Dawson Brothers. 144 pp., 9 pl..

Bizzarro, M. 1995. The Middle Devonian chonetoidean brachiopods from the Hamilton Group of New York. Documents des Laboratoires de Géologie de Lyon, 136: 149-189, 13 fig., 4 pl..

Boucot, A. J. 1959a. A new family and genus of Silurian orthotetacid brachiopods.

Journal of Paleontology, 33(1): 25–28, pl. 3.
Boucot, A. J., 1959b. Brachiopods of the Lower Devonian rocks at Highland Mills, New York. Journal of Paleontology, 33(5): 727-769. Pl. 90-103.
Boucot, A. J., Field, M. T., Fletcher, R., Forbes, W. H., Naylor, R. S., and Pavlides, L. 1964a. Reconnaissance bedrock geology of the Presque Isle Quadrangle, Maine. Maine Geological Survey, Quadrangle Mapping Series No.2. 123pp.
Boucot, A. J., Johnson, J. G., and Staton, R. D. 1964b. On some atrypoid, retzioid, and athyridoid Brachiopoda. Journal of Paleontology, 38: 805–822, pl. 125–128.
Boucot, A. J., Johnson, J. G., and Staton, R. D. 1965. Athyrididina. In R. C., Moore (ed.), Treatise on invertebrate paleontology, Part H, brachiopoda, Vol.2. Geological Society of America, INC. & University of Kansas. p. 654-667.
Bradley, D., and Hanson, L., 1989, Turbidites and me'langes of the Madrid Formation, central Maine. In: A.W. Jr., Berry (ed.), Guidebook for Field trips in southern and west-central Maine. New England Intercollegiate Geological Conference 81st Annual Meeting, p. 183–199.
Branson, E. B., and Williams, J. S. 1922. Fauna of the Middle Devonian of southeastern Missouri. Missouri Bureau of Geology and Mines, Ser. 2, 17: 132-149, 5pl.
Brett, C. E., Dick, V. B., and Baird, G. C. 1991. Comparative taphonomy and paleoecology of Middle Devonian dark gray and black shale facies from western New York. In: E., Landing, and C. E., Brett (eds.), Dynamic stratigraphy and depositional environments of the Hamilton Group (Middle Devonian) in New York State, part II, New York State Museum/Geological Survey, Bulletin 469: 5-36.
Brett, C. E. and Baird, G. C. 1996. Middle Devonian sedimentary cycles and sequences in the northern Appalachian Basin. In B. J., Witzke, and J., Day (eds.), Paleozoic Sequence Stratigraphy: View from the North American Craton. Geological Society of America Special Paper, no. 306, p. 213-241.
Brett, C. E., Bartholomew, A. J., and Baird, G. C. 2007. Biofacies recurrence in the Middle Devonian of New York state: an example with implications for evolutionary paleoecology. Palaios, 22: 306-324.
Brett, C. E., Dick, V.B., and Baird, G. C. 1991. Comparative taphonomy and paleoecology of Middle Devonian dark gray and black shale facies from western New York. In: E., Landing, and C. E., Brett (eds.), Dynamic stratigraphy and depositional environments of the Hamilton Group (Middle Devonian) in New York State, part II, New York State Museum/Geological Survey Bulletin, 469: 5-36.
Bronn, H. G. 1848. Index palaeontologicus oder Uebersicht der bis jetzt bekannten fossilen organismen, unter Mitwirkung der HH. Prof. H.R. Goppert und Herm. V. Meyer. Erste Abtheilung. A. Nomenclator palaeontologicus, in alphabetischer ordnung, 1382 pp. Stuttgart: E. Schweitzerbart' sche Verlagshandlung.
Bronn, H. G. 1862. Die Klassen und Ordnungen der Weichthiere (Malacozoa), vol. 3(1). C. F. Winter'sche Verlagshandlung. Leipzig & Heidelberg. 518 pp., 44 pl.
Brower, J. C., and Nye, O. B. J. 1987. Quantitative analysis of paleocommunities in the lower part of the Hamilton Group near Cazenovia, New York. In: C. E., Brett (ed.), Dynamic stratigraphy and depositional environments of the Hamilton Group (Middle Devonian) in New York State, part II, New York State Museum and Science Bulletin.

469: 37-74.

Bruguière, J. G. 1797. Vers, Coquilles, Mollusques et Polypiers. Tableau encyclopédique et méthodique des trois règnes de la nature. Agasse. Paris, 2: 96–314.

Brunton, C. H. C., Cocks, L. R. M., and Dance, S. P. 1967. Brachiopods in the Linnaean collection. Proceedings Linnaean Society, London, 178: 161-183.

Bublichenko, N. L. 1956. Nekotorye novye predstaviteli brakhiopod Devona i Karbona rudnogo Altaia i Sary-Arka [Some new representative brachiopods of the Devonian and Carboniferous of the Rudny-Altai and Sari-Arka]. Akademiia Nauk Kazakhskoi SSR, Izvestiia, Seriia Geologicheskaia, 23: 93–104, 1 pl.

von Buch, L. 1834. Über Terebrateln, mit einem Versuch sie zu classificiren und zu beschreiben. Physikalische Abhandlungen Königliche Akademie für Wissenchaften aus den Jahre 1833: 1-124, pl. 1-3.

Budai, J. M., Martini, A. M., Walter, L. M., and Ku, T. C. W. 2002. Fracture-fill calcite as a record of microbial methanogenesis and fluid migration: a case study from the Devonian Antrim Shale, Michigan Basin. Geofluids. 2: 163-183.

Buehler, E. J. 1969. Paleontological notes cylindrical borings in Devonian shells. Journal of Paleontology, 43 (5): 1291.

Caley, J. F. 1943. Paleozoic geology of the London area, Ontario. Geological Survey of Canada, 237(2470): 1-171.

Camp, M. J., and Hatfield, C. B. 1991. Middle Devonian (Givetian) Silica Formation of Northwest Ohio-Description and road log. Ohio Journal of Science, 91(1): 27-34.

Carter, J. L., Johnson, J. G., Gourvennec, R., and Hou, H. 1994. A revised classification of the spiriferid brachiopods. Annals of the Carnegie Museum, 63(4): 327–374.

Caster, K. E. 1939. A Devonian fauna from Colombia. Bulletin of American Paleontology, 24: 1–218, pl. 1–14.

Castle, J. W. 2001a. Appalachian basin stratigraphic response to convergent-margin structural evolution. Basin Research, 13: 397-418.

Castle, J. W. 2001b. Foreland-basin sequence response to collisional tectonism. Geological Society of America Bulletin, 113(7): 801-812.

Catacosinos, P. A., Daniels, P. A. Jr., Harrison, W. B. III. 1990. Structure, stratigraphy, and petroleum geology of the Michigan Basin. In: M. W., Leighton, R. D., Kolata, D. F., Oltz, , and J. J., Eidel (eds), Interior cratonic basins. American Association of Petroleum Geologists, Memoir 51: 561-601.

Chatterton, B. D. E. 1973. Brachiopods of the Murrumbidgee Group, Taemas, New South Wales. Bureau of Mineral Resources, Geology and Geophysics, Bulletin 137: 1-146. 35 pl.

Clarke, J. M., and Swartz, C. K. 1913. Systematic paleontology of the Upper Devonian deposits of Maryland. Maryland Geological Survey of Middle and Upper Devonian, pp. 536-699, pl. 45-73.

Cleland, H. F. 1911. The fossils and stratigraphy of the Middle Devonic of Wisconsin. Wisconsin Geological and Natural History Survey Bulletin, 21: 1-222, pl. 1-53.

Cloud, P. E. J. 1942. Terebratuloid Brachiopoda of the Silurian and Devonian. Geological Society of America, Special Papers, 38: 1–182, pl. 1–26.

Cocks, L. R. M., and Rong, J. (eds.) 2000. Strophomenida. In: R. L., Kaesler (ed.), Treatise on invertebrate paleontology, Part H, brachiopoda, Revised Vol. 2: Linguliformea, Craniiformea, and Rhynchonelliformea (part). Geological Society of America, INC. & University of Kansas. p. 216-349.

Conrad, T. A. 1838. Report on the Palaeontological department of the survey. New York Geological Survey, Annual Report, 2: 107-119.

Conrad, T.A. 1839. Descriptions of new species of organic remains. Second annual report on the Palaeontological department of the survey. New York State Geological Survey, Second Annual Report, p. 57-66.

Conrad, T. A. 1841. Fifth annual report on the palaeontology of the state of New York. New York Geological Survey, Annual Report, 5: 25-57.

Conrad, T. A. 1842. Observations on the Silurian and Devonian systems of the United States, with descriptions of new organic remains. Academy of Natural Sciences of Philadelphia, 8(2): 228-280, pl. 12-17.

Cooper, G. A. 1930a. Stratigraphy of the Hamilton Group of New York, part 1. American Journal of Science, 5th Series, 19(110):116-134.

Cooper, G. A. 1930b. Stratigraphy of the Hamilton Group of New York, part 2. American Journal of Science, 5th Series, 19(111):214-236.

Cooper, G. A. 1933. Stratigraphy of the Hamilton Group of eastern New York, part 1. American Journal of Science, 5th Series, 26(156):537-551.

Cooper, G. A. 1934. Stratigraphy of the Hamilton Group of eastern New York, part 2. American Journal of Science, 5th Series, 27(157):1-12.

Cooper, G. A. 1936. Studies of Middle Devonian rocks in the Mid-West. Explorations and field-work of the Smithsonian Institution, 1935: 9-12.

Cooper, G. A. 1942. New genera of North American brachiopods. Journal of Washington Academy of Sciences, 32(8): 228–235.

Cooper, G. A. 1945. New species of brachiopods from the Devonian of Illinois and Missouri. Journal of Paleontology, 19(5): 479-489, pl. 63-64.

Cooper, G. A., Butts, C., Caster, K. E., Chadwick, G. H., Goldring, W., Kindle, E. M., Kirk, E., Merriam, C. W., Swartz, F. M., Warren, P. S., Warthin, A. S., and Willard, B. 1942. Correlation of the Devonian sedimentary formations of North America. Bulletin of the Geological Society of America, 53(12): 1729-1793. 1pl.

Cooper, G. A., and Cloud, P. E. 1938. New Devonian Fossils from Calhoun County, Illinois. Journal of Paleontology, 12(5): 444-460.

Cooper, G. A., and Dutro, J. T. J. 1982. Devonian brachiopods of New Mexico. Bulletins of American Paleontology, 82–83:1-215, 45 pl., pl. A–C.

Cooper, G. A., and Warthin, A. S., 1942. New Devonian (Hamilton) correlations: Bulletin of the Geological Society of America, 53: 873-888.

Copper, P. 1973. New Siluro-Devonian atrypoid brachiopods. Journal of Paleontology, 47(3): 484-500, 3 pl.

Copper, P. 1978. Devonian atrypids from western and northern Canada. Geological Association of Canada Special Papers, 18: 289–331, 7 pl.

Cozzens, I. 1846. Descriptions of three new fossils from the Falls of Ohio. Annals of the Lyceum of Natural History of New York, 4: 157-159.

M'Coy, F. 1844. A Synopsis of the Characters of the Carboniferous Limestone Fossils of Ireland. Printed at the University Press by M. H. Gill. Dublin. 207 pp., 29 pl.

Dalman, J. W. 1828. Uppställning och Beskrifning af de i Sverige funne Terebratuliter. Kongliga Svenska Vetenskapsakademien Handlingar for 1827, 3: 85–155, pl. 1–6.

Davidson, T. 1848. Mémoire sur les Brachiopodes du Système Silurien supérieur de l'Angleterre. Société Géologique de France, Bulletin (series 2) 5: 309-338, 370-374, 2 pl.

Davidson, T. 1858. Palaeontological notes on the Brachiopoda. No. 1. On the genera and sub-genera of Brachiopoda that are provided with spiral appendages for the support of the oral arms, and species so constructed, which have been discovered in British Carboniferous strata. Geologist, 1: 409–416, 457–472.

Davidson, T. 1859. A monograph of the British fossil Brachiopoda, Carboniferous, vol. 2, part 5. Palaeontographical Society Monograph. London. p. 1–280, pl. 1–55.

Davidson, T. 1864. A monograph of the British fossil brachiopoda. Palaeontographical Society, Monograph, 16: 1-56, pl. 1-9.

Davidson, T. 1881. On genera and species of spiral-bearing Brachiopoda from specimens developed by Rev. Norman Glass: with notes on the results obtained by Mr. George Maw from extensive washing of the Wenlock and Ludlow shales of Shropshire. Geological Magazine (new series, Decade II), 8(1): 1–13.

Davidson, T. 1882. A monograph of the British fossil brachiopoda (vol.5, part 1: Devonian and Silurian supplements). Palaeontographical society, Monograph, 36: 1-134, pl. 1-7.

Day, J., and Copper, P. 1998. Revision of latest Givetian-Frasnian Atrypida (Brachiopoda) from central North America. Acta Palaeontologica Polonica, 43(2): 155-204.

Defrance, M. J. L. 1828. Térébratules fossiles. In: G., Cuvier, (ed.), Dictionnaire des Sciences Naturelles, vol. 52-53. F. G. Levrault. Strasbourg. P. 147-167, vol. 52; p. 434-435, vol. 53.

Dice, L. R. 1945. Measures of the amount of ecological association between species. Ecology, 26: 297-302.

Donato, S.V.R. 2003. Paleoecology of the middle Devonian *Leiorhynchus* shale and coral biostrome of the Hungry Hollow formation in southwestern Ontario: Master's Thesis, University of Western Ontario, 147 pp.

Donohoe, H. V., and Pajari, G. 1973. The age of the Acadian deformation in Maine-New Brunswick. Maritime Sediments, 9: 78-82.

Driscoll, E. G., Hall, D. D., and Nussmann, D. G. 1965. Morphology and paleoecology of the brachiopod *Leiorhynchus kelloggi* Hall, Middle Devonian, Ohio, Michigan, Ontario. Journal of Paleontology, 39(5): 916-933.

Driscoll, E. G., and Mitchell, S. W. 1969. Stratigraphy and Tetracoral Fauna of the Lower Arkona Formation, Middle Devonian, Ontario and Michigan. Michigan Academician, 1: 117-141.

Duméril, A. M. C. 1806. Zoologie analytique ou méthode naturelle de classification des animaux. Allais. Paris. 344 pp.

Dunbar, C.O. 1960. Historical Geology, John Wiley and Sons, Inc., New York, 500pp.

Eaton, A. 1832a. Geological equivalents. American Journal of Science and Arts (1831), 21: 132-138.

Eaton, A. 1832b. Geological textbook for aiding the study of North American geology, 2nd edit. Albany. 134 pp.

Eichwald, E. von. 1829. Zoologia specialis. St. Petersburg, Golike, 1: 1-314.

Ehlers, G. M., and Cooley, M. E. 1927. Discovery of a Hamilton fauna in southeastern Michigan. Contributions from the Museum of Paleontology, the University of Michigan, 2(13): 231-236.

Ehlers, G. M., and Kesling, R. V. 1970. Devonian strata of Alpena and Presque Isle Counties, Michigan. Guidebook for the field trip of the North-Central Section of the Geological Society of America East Lansing Meeting, 130 pp.

Ehlers, G. M., and Kline, V. 1934. Revision of Alexander Winchell's types of brachiopods from the Middle Devonian Traverse Group of rocks of Michigan. Contributions from the Museum of Paleontology, the University of Michigan, 4(10): 143-176, 4 pl., 1 fig.

Ehlers, G. M., Stumm, E. C., and Kesling, R. V. 1951. Devonian rocks of southeastern Michigan and northwestern Ohio. Prepared for the stratigraphic field trip of the Geological Society of America, Detroit Meeting, p. 1-40, 5 pl.

Ehlers, G. M., and Wright, J. D. 1955. The type species of *Spinocyrtia fredericks* and new species of this brachiopod genus from southwestern Ontario. Contributions from the Museum of Paleontology, University of Michigan, 13(1):1-32, 11 pl.

Ehlers, G. M., and Wright, J. D. 1975. New species of the brachiopod *Cyrtina* from the Middle Devonian Hamilton strata of southwestern Ontario. Contributions from the Museum of Paleontology, University of Michigan, 24(14): 149-162.

Ettensohn, F. R. 1985a. The Catskill delta complex and the Acadian orogeny: A model. In: D. L., Woodrow, and W. D., Sevon (eds.), The Catskill delta. Geological Society of America Special Paper 201:39–49.

Ettensohn, F. R. 1985b. Controls on the development of Catskill Delta complex basin facies. In D. L., Woodrow, and W. D., Sevon (eds.), The Catskill Delta. Geological Society of America Special Paper, No. 201, p. 65-78.

Ettensohn, F. R., 1987. Rates of relative plate motion during the Acadian Orogeny based on spatial distribution of black shales. Journal of Geology, 95: 572-582.

Fagerstrom, J. A. 1961. The fauna of the Middle Devonian Formosa Reef Limestone of southwestern Ontario. Journal of Paleontology, 35(1): 1-48.

Fagerstrom, J. A. 1971. Brachiopods of the Detroit River Group (Devonian) from southwestern Ontario and adjacent areas of Michigan and Ohio. Geological Survey of Canada, 204: 1-96, 8pl.

Fisher, D. W. 1951. Marcasite fauna in the Ludlowville Formation of western New York. Journal of Paleontology, 25(3): 365-371, pl. 55.

Fisher, J. H., Barratt, M. W., Droste, J. B., and Shaver, R. H. 1988. Michigan Basin. In: L. L., Sloss (ed.), Sedimentary cover- North American craton. U. S. : Boulder, Colorado, Geological Society of America, the Geology of North America. D-2: 361-383.

Frederiks, G. N. 1911. Zametka o nekotopykh" verkhne-paleozoiskikh" okamenelostyakh iz" okrectnostei gor. Krasnoufimska [Bemerkung über einige oberpalaeozoische Fossilien von Krasnoufimsk]. Prilozhenie k protokolam" zasedanii Obshchestva Estestvoispytatelei pri Imperatorckom" Kazanskom" universitete, 269: 1–12, 1 pl.

Frederiks, G. N. 1916. Paleontologicheskiia zametki. 2. O. Nekotorykh' verkhne-Paleozoiskikh' Brakhiopodakh' Evrazii [Paleontological notes. 2. On some upper Paleozoic Brachiopoda of Eurasia]. Comité Géologique, Mémoires (new series) 156: 1–87, 5 pl.

Frederiks, G. N. 1918. On the adaptation of the apicalapparatus subdivision to the Brachiopoda's classification. Ezhegodnik Russkogo Paleontologicheskogo Obshchestva [Annuaire de la Société Paléontologique de Russie], 2: 85–91.

Frederiks, G. N. 1924. Paleontologitcheskie ztoudy. 2: O verkhne kamennougolnykh spiriferidakh Ourala [Paleontological studies. 2: On Upper Carboniferous spiriferids from the Urals]. Izvestyia geologicheskogo Komiteta, 38(3): 295–324.

George, M. E., and Wright, E. P. 1959. *Leiopteria rafinesquii* Hall and a new species of the genus from the Thedford-Arkona region of southwestern Ontario. Contributions from the Museum of Paleontology, University of Michigan, 15(1): 1-13. 2pls.

George, T. N. 1931. *Ambocoelia* Hall and certain similar British Spiriferidae. Geological Society of London, Quarterly Journal, 87: 30–61, pl. 3–5.

Gill, T. 1871. Arrangement of the families of mollusks prepared for the Smithsonian Institution. Smithsonian Miscellaneous Collections, 227: 1–49.

Goldman, D., and Mitchell, C. E. 1990. Morphology, Systematics, and evolution of Middle Devonian ambocoeliidae (Brachiopoda), western New York. Journal of Paleontology, 64(1): 79-99.

Gorjansky, V. I., and Popov, L. E. 1985. Morfologiia, systematicheskoe polozhenie i proiskhozhdenie bezzamkovykh brakhiopods karbonatnoi rakovinoi [Morphology, systematic position and origin of the inarticulate brachiopods with calcareous shells]. Paleontologicheskii Zhurnal, 3: 3–14, 1 pl.

Grabau, A. W. 1899. Geology and palaeontology of Eighteen-Mile Creek and the lake shore sections of Erie County, New York. Buffalo Society of Natural Science, 6(2): 93-403.

Grabau, A. W. 1931. Studies for students. Series I, Palaeontology. Studies of Brachiopoda, Part 2. Reprinted from the Science Quarterly of the National University of Peking 2: 397–422.

Grabau, A. W., and Shimer, H. W. 1909. North American index fossils. Invertebrates, Vol. 1. New York: A. G. Seiler & Company. 853pp.

Grabau, A. W., and Reed, M. 1910. Mutations of *Spirifer mucronatus*. Advance Printing, Process of the 7th International Zoology Congress, p. 1-2, Boston Meeting, August 19-20, 1907.

Grabau, A. W, and Reed, M. 1912. Mutations of *Spirifer mucronatus*. Process of the 7th International Zoology Congress, Boston Meeting, p. 767-768, August 19-20, 1907.

Gray, J. E. 1840. Synopsis of the contents of the British Museum, 42nd edition. London: British Museum. 370 pp.

Griesemer, A. D. 1965. Middle Devonian brachiopods of southeastern Wisconsin. The Ohio Journal of Science, 65(5): 241-295, pl. 1-6.

Hall, J. 1843. Geology of New York, Part IV, comprising the survey of the fourth geological district. Albany, N. Y. 683pp.

Hall, J. 1850. On the Brachiopoda of the Silurian Period. Proceedings of the American

Association for the Advancement of Science, 2: 247–351.
Hall, J. 1852. Containing descriptions of the organic remains of the lower middle division of the New-York system. Palaeontology of New York, 2: 1-362.
Hall, J. 1857. Descriptions of new species of Palaeozoic fossils from the Lower Helderberg, Oriskany Sandstone, Upper Helderberg, Hamilton and Chemung Groups. New York State Cabinet of Natural History, Annual Report, 10: 41-186.
Hall, J. 1858. Palaeontology of Iowa. In: J., Hall, and J. D., Whitney (eds.), Report of the geological survey of the state of Iowa: embracing the results of investigations made during portions of the years 1855, 56 & 57, 1(2): 473-724, 29 pl.
Hall, J. 1859. Contributions to the Palaeontology of New York. New York State Cabinet of Natural History, Annual Report, 12: 8-110.
Hall, J. 1860a. Contributions to the Palaeontology of New York; 1858 & 1859. Appendix, Part F, of the 13th Annual Report of the Regents of the University of the State of New York on the condition of the State Cabinet of Natural History, and the Historical and Antiquarian Collection annexed thereto. Albany. p. 53–125.
Hall, J. 1860b. Descriptions of new species of fossils from the Hamilton Group of western New York, with notices of others from the same horizon in Iowa and Indiana. New York State Cabinet of Natural History, Annual Report, 13: 76-94.
Hall, J. 1861. Descriptions of new species of fossils from the Upper Helderberg, Hamilton and Chemung Groups; with observations upon previously described species. New York State Cabinet of Natural History, Annual Report, 14: 99-109.
Hall, J. 1862. Contributions to Palaeontology; Comprising descriptions of new species of fossils, from the Upper Helderberg, Hamilton and Chemung Groups. New York State Cabinet of Natural History. Annual Report, 15: 27-115, pl. 1-11.
Hall, J. 1863a. Descriptions of new species of Brachiopoda, from the Upper Helderberg, Hamilton and Chemung Groups. New York State Cabinet of Natural History, Annual Report, 16: 19-37.
Hall, J. 1863b. Observations upon some of the Brachiopoda, with references to the characters of the genera, Cryptonella, Centronella, Meristella, Trematospira, Rhynchospira, Retzia, Leptocoelia, and allied forms. New York State Cabinet of Natural History, Annual Report, 16: 38-59.
Hall, J. 1867. Descriptions and figures of the fossil Brachiopoda of the Upper Helderberg, Hamilton, Portage and Chemung groups. Palaeontology of New York, 4(1): 1-428, 63 pl.
Hall, J. 1883. Brachiopoda, plates and explanations. New York State Geologist, Annual Report 2, pl. 34-61.
Hall, J., and Clarke, J. M. 1892a. An introduction to the study of the genera of Palaeozoic Brachiopoda. New York State Geologist for 1891, Palaeontology, Annual Report, 11:139-300, pl. 1-22.
Hall, J., and Clarke, J. M. 1892b. An introduction to the study of the genera of Palaeozoic Brachiopoda. New York Geological Survey, Palaeontology, 8(1): 1-367, 20 pl.
Hall, J. 1894a. An introduction to the study of the brachiopoda intended as a hand book for the use of students. Thirteenth Annual Report State Geologist for the Year 1893, 2(2): 749-1015.

Hall, J., and Clarke, J. M. 1894b. An introduction to the study of the genera of Palaeozoic brachiopoda, Palaeontology of New York, 8(2): 1-394.

Hall, J., and Clarke, J. M. 1894c. The evolution of the genera of the Palaeozoic Brachiopoda. New York State Museum, 47th Annual Report. Albany. p. 803–851, 943–1137. Summary, p. 803–834; Table of Classification, p. 835–840; Description of New Species Figured in Volume VIII, Part 2, p. 841–851; An introduction to the study of the Brachiopoda intended as a hand book for the use of students. Part II: The Genera of Brachiopoda, p. 943–1100; The Evolution and Classification of the Genera of the Brachiopoda, p. 1101–1124; Table of Classification, p. 1125–1132.

Hammer, Ø., and Harper, D. A. T. 2006. Paleontological data analysis. Blackwell Publishing, Malden, 351pp.

Hammer, Ø., and Harper, D. A. T. 2007. PAST-PAlaeontological STatistics, ver. 1.67. http://folk.uio.no/ohammer/past.

Harland, W. B. , Cox, A. V., Llewellyn, P. G., Pickton, C. A. G., Smith, A. G., and Walters, R. 1982. A geologic time scale. Cambridge Earth Science Series, Cambridge University Press, 131pp.

Harper, C. W., Boucot, A. J., and Walmsley, V. G. 1969. The Rhipidomellid brachiopod subfamilies HETERORTHINAE and PLATYORTHINAE (New). Journal of Paleontology, 43(1): 74-92, pl. 15-17.

Hay, B. J. , and Cisne, J. L. 1988. Deposition in the oxygen-deficient Taconic foreland basin, Late Ordovician. In: B. D., Keith (ed.), The Trenton Group (Upper Ordovician Series) of Eastern North America, American Association of Petroleum Geology, 29: 113-134.

Henry, T. W., and Gordon, M. J. 1985. Chesterian davidsoniacean and orthotetacean brachiopods, Ozark region of Arkansas and Oklahoma. Journal of Paleontology, 59(1): 32–59.

Hoare, R. D., and Steller, D. L. 1969. Inarticulate brachiopods of the Silica Formation (Devonian), Ohio and Michigan. Contributions From The Museum of Paleontology, University of Michigan, 22(20): 263-272. 2pl.

Holmer, L. E., and Popov, L. E. (eds.) 2000. Lingulata. In: R. L., Kaesler (ed.), Treatise on invertebrate paleontology, Part H, Brachiopoda revised volume 2 & 3: Linguliformea, Craniiformea, and Rhynchonelliformea (part). Geological Society of America, INC. & University of Kansas, Boulder, Colorado, and Lawrence, Kansas. p. 32-146.

Howard, C., Brunton, C., Lazarev, Grant, R. E., and Jin, Y. (eds.) 2000. Productidina. In: R. L., Kaesler (ed.), Treatise on invertebrate paleontology, Part H, Brachiopoda revised volume 2 & 3: Linguliformea, Craniiformea, and Rhynchonelliformea (part). Geological Society of America, INC. & University of Kansas, Boulder, Colorado, and Lawrence, Kansas. p. 424-609.

Howell, P.D., and van der Pluijm, B. A. 1990. Early history of the Michigan basin: Subsidence and Appalachian tectonics. Geology, 18: 1195-1198.

Howell, P.D., and van der Pluijm, B. A. 1999. Structural sequences and styles of subsidence in the Michigan Basin, Bulletin of Geological Society of America, 111(7): 974-991.

Imbrie, J. 1955. New species of brachiopods from the Traverse Group (Devonian) of

Michigan. American Museum Novitates, 1754: 1-7.

Imbrie, J. 1959. Brachiopods of the Traverse Group (Devonian) of Michigan, Part 1. Dalmanellacea, Pentameracea, Strophomenacea, Orthotetacea, Chonetacea, and Productacea. Bulletin of the American Museum of Natural History, 16(4): 345-410, pl. 48-67.

Ivanova, E. A. 1959. K systematike i evolyutsii spiriferid (Brachiopoda) [On the systematics and evolution of the spiriferids (Brachiopoda)]. Paleontologicheskii Zhurnal, 4: 47–63, fig. 1–9, pl. 2.

Ivanova, E. A. 1972. Osnovnyye zakonomernosti evolyutsii spiriferid (Brachiopoda) [Main features of spiriferid evolution (Brachiopoda)]. Paleontologicheskii Zhurnal, 3: 28–42.

Jaccard, P. 1912. The distribution of the flora of the alpine zone. New Phytologist, 11: 37-50.

Johnson, J. G. 1971. Timing and coordination of orogenic, epeirogenic, and eustatic events. Geological Society of America Bulletin, 82:3263-3298.

Johnson, J. G. (ed.) 2006. Cyrtospiriferoidea. In: R. L., Kaesler (ed.), Treatise on invertebrate paleontology, Part H, brachiopoda, Revised Vol. 5: Rhynchonelliformea (part). Geological Society of America, INC. & University of Kansas. p. 1722-1732.

Johnson, J. G., and Norris, A. W. 1972. *Tecnocyrtina*, a new genus of Devonian brachiopods. Journal of Paleontology, 46(4): 565-572, 2 pl.

Johnson, M. D., Russell, D. J., and Telford, P. G. 1985. Oil shale assessment project, drillholes for regional correlation 1983/84. Ontario Geological Survey, Open File Report, 5565. 49pp.

Kelly, W. A., and Smith, G. W. 1947. Stratigraphy and Structure of Traverse group in Afton-Onaway Area, Michigan. American Association of Petroleum Geologists, 31(3): 447-469.

Kesling, R. V. 1953a. Ostracods of the Family Drepanellidae from the Arkona Shale of Ontario. Contributions from the Museum of Paleontology, University of Michigan, 10(8):193-202. 1pl.

Kesling, R.V. 1953b. Ostracods of the Family Hollinidae from the Arkona Shale of Ontario. Contributions from the Museum of Paleontology, University of Michigan, 10(9):203-219. 4pls.

Kesling, R.V. 1953c. Ostracods of the Family Aechminidae from the Arkona Shale of southern Ontario. Contributions from the Museum of Paleontology, University of Michigan, 11(1):1-10. 1pl.

Kesling, R.V. 1969. A new brittle-star from the Middle Devonian Arkona shale of Ontario. Contributions from the Museum of Paleontology, University of Michigan, 23(2): 37-51.

Kesling, R.V. 1970. *Drepanaster wrighti*, a new species of brittle-star from the middle Devonian Arkona shale of Ontario. Contributions from the Museum of Paleontology, University of Michigan, 23(4): 73-79.

Kesling, R.V. 1971. *Proctothylacocrinus berryorum*, a new crinoid from the Middle Devonian Arkona Shale of Ontario. Michigan. University of Michigan Museum of Paleontology Papers on Paleontology, 23: 343-347.

Kesling, R. V. 1982a. *Acinetaster konieckii*, a new brittle-star from the Middle

Devonian Arkona Shale. Contributions from the Museum of Paleontology, University of Michigan, 26(5): 71-81, 2pls.

Kesling, R. V. 1982b. *Arkonaster*, a new multi-armed starfish from the Middle Devonian Arkona Shale of Ontario. Contributions from the Museum of Paleontology, University of Michigan, 26(6): 83-115, 7pls.

Kesling, R. V., Segall, R. T., and Sorensen, H. O. 1974. Devonian strata of Emmet and Charlevoix Counties, Michigan. University of Michigan Museum of Paleontology Papers on Paleontology, 7: 1-187.

Kesling, R. V., and Wright, J. D. 1965. Two New Middle Devonian Species of the Starfish *Devonaster* from Southwestern Ontario. Contributions from the Museum of Paleontology, University of Michigan, 20(2):49-61, 4pls.

Keyes, S. W., and Pitrat, C. W. 1978. Spiriferid brachiopods from the Traverse Group of Michigan: Cyrtinacea. Journal of Paleontology, 52(2): 221-233.

Kindle, E. M. 1896. The relation of the fauna of the Ithaca group to the faunas of the Portage and Chemung. Bulletins of American Paleontology, 2(6): 1-56, 1 pl.

Kindle, E. M. 1901. The Devonian fossils and stratigraphy of Indiana. Indiana Department of Geology and National History, Annual Report, 25: 529-782, 31pl.

King, R. E. 1846. Remarks on certain genera belonging to the class Palliobranchiata. Annals and Magazine of Natural History (series 1), 18: 26–42, 83–94.

Kirk, E., and Amsden, T. W. 1952. Upper Silurian brachiopods from southeastern Alaska. U.S. Geological Survey, Professional Paper, 233-C: 53-66.

Klein, G. de V. 1991. Origin and evolution of North American cratonic basins. South African Journal of Geology, 94:3-18.

Koken, E. F. R. 1889. Ueber die Entwickelung der Gastropoden vom Cambrium bis zur Trias. Neues Jahrbuch für Mineralogie, Geologie und Palaeontologie, 6: 305-484, pl. 10-14.

Kralik, J. III. 1992. Paleosynecology of the Hungry Hollow Formation biostrome (Middle Devonian: Givetian) in southwestern Ontario. Master's thesis. The University of Toledo. 273pp.

Kuhn, O. 1949. Lehrbuch der Paläozoologie. E. Schweizerbart'sche Verlagsbuchhandlung. Stuttgart. 326 pp.

de Lamarck, J. P. B. A. de M. 1801. Système des Animaux sans Vertèbres, ou Tableau Général des Classes, des Ordres, et des Genres de ces Animaux. Déterville, Paris. 432pp.

Landing, E.D., and Brett, C. E. 1987. Trace fossils and regional significance of a Middle Devonian (Givetian) disconformity in southwestern Ontario. Journal of Paleontology, 61(2): 205-230.

Laudon, L. R. 1936. Notes on the Devonian crinoid fauna of the Cedar Valley Formation of Iowa. Journal of Paleontology, 10(1): 60-66.

Lazarev, S. S. 1989. Sistema Devonskikh brakhiopod podotriada Strophalosiidina [Systematics of Devonian brachiopods of suborder Strophalosiidina]. Paleontologicheskii Zhurnal, 2: 27–39, pl. 3.

Léveillé, c. 1835. Aperçu géologique de quelques localités très riches en coquilles sur les frontières de France et de Belgique. Mémoire de la Société Géologique de la France, 2: 29-40, pl. 2.

Li, R., and Jones, B. 2003. Middle Devonian brachiopods from the Bird Fiord Formation, Arctic Canada. Journal of Paleontology, 77(2): 243-266.

Linnaeus, C. F. 1758. Systema naturae, sive regna tria naturae systematice proposita classes, ordines, genera et species. Edition 10, Tome 1, Regnum animale, reformata, Stockholm. 824 pp.

Linsley, D. M. 1994. Devonian paleontology of New York. Paleontological Research Institution, Special Publication 21: 1-472.

Logan, W.E., 1863, Report on the geology of Canada. Geological Society of Canada. 983pp.

Manankov, I. N. 1979. Strofomenidy pozdnego paleozoia Sibiri i Arktiki [Strophomenids of the Late Paleozoic of Siberia and the Arctic]. Akademiia Nauk SSSR, Paleontologicheskii Institut, Trudy 171:1–101, pl. 1–13.

McCollum, L. B., 1986. Revised stratigraphy, sedimentology, and paleoecology of the Ledyard Member, Ludlowville Formation, New York. In: C. E., Brett (ed.), Dynamic stratigraphy and depositional environments of the Hamilton Group (Middle Devonian) in New York State, part II, New York State Museum and Science Survey Bulletin, 469: 107-128.

McLaren, D. J., and Norris, A. W. 1964. Fauna of the Devonian Horn Plateau Formation, district of Mackenzie. Geological Survey of Canada, 114:1-74, 17pl.

Meek, F. B. 1868. Remarks on the geology of the Valley of Mackenzie River, with figures and descriptions of fossils from that region, in the Museum of the Smithsonian Institution, principally collected by the Late Robert Kennicott, Esq. Chicago Academy of Sciences, Transactions, 1(3): 61-114, pl. 11-15.

Meek, F. B. 1877. Palaeontology. United States Geological Exploration of the 40th parallel by Clarence King, 4(1): 1-197, pl. 1-17.

Menke, C. T. 1828. Synopsis methodica molluscorum generum omnium et specierum earum quae in Museo Menkeano adservantur. G. Uslar. Pyrmonti. 91 pp.

Miller, K. B. 1986. High-resolution correlation within a storm-dominated muddy Epeiric Sea: taphofacies of the Middle Devonian Wanakah Member, western New York. Brett, C. E. ed. Dynamic stratigraphy and depositional environments of the Hamilton Group (Middle Devonian) in New York State, part II, New York State Museum and Science Survey Bulletin, 469: 129-152.

Miller, S. A. 1883. The American Palaeozoic fossils: a catalogue of the genera and species, with names of authors, dates, places of publication, groups of books in which found, and the etymology and signifcation of the words, and an introduction devoted to the stratigraphical geology of the Palaeozoic rocks. 2nd edition, Cincinnati: privately published by the author, Ohio. p. 247-334.

Miller, S. A. 1889. North American geology and paleontology. Cincinnati, Ohio, 718pp., 1265 figs.

Mitchell, S. W. 1967. The stratigraphy of the Silica Formation of Ohio and the Hungry Hollow Formation of Ontario, with paleogeographic interpretations. Papers of the Michigan Academy of Science, Arts, and Letters, 52: 175-196.

Mitchell, S. W. 1967. Stratigraphy of the silica formation of Ohio and the Hungry Hollow formation of Ontario, with paleogeographic interpretations. Papers of the Michigan Academy of Science, Arts and Letters, 3: 175-196.

Modzalevskaya, T. L. 2007. The earliest Terebratulids. Palaeontology, 50(4): 869–882, 2 pl.

Mook, C. C. 1915. Statistical study of variation in *Spirifer mucronatus*. Annual New York Academic Science, 26: 1-214.

Moore, R. C. 1952. Brachiopoda. In: R. C., Moore, C. G., Lalicker, and A. G., Fischer (eds.), Invertebrate fossils. McGraw-Hill. New York. p. 197–267.

Morris, J. 1854. A catalogue of British fossils: comprising the genera and species hitherto described; with references to their geological distribution and to the localities in which they have been found, 2nd edition. London: printed and published by the author. 372pp.

Mottequin, B. 2008. Late Middle to Late Frasnian Atrypida, Pentamerida, and Terebratulida (Brachiopoda) from the Namur–Dinant Basin (Belgium), Geobios, 41: 493–513.

Muir-Wood, H. M. 1955. A history of the classification of the Phylum Brachiopoda. London: British Museum (Natural History). 124 pp.

Muir-Wood, H. M. 1962. On the morphology and classification of the brachiopod suborder CHONETOIDEA. British Museum (Natural History), Monograph. 132 pp., 16 pl.

Muir-Wood, H. M., and Cooper, G. A. 1960. Morphology, classification and life habits of the Productoidea (Brachiopoda). Geological Society of American Memoir, 81: 1-447, 8 fig., 135 pl.

Murchison, R. I. 1840. Description de quelques unes des coquilles fossiles les plus abondantes dans les couches devoniennes du Bas-Boulonnais. Bulletin de la Societé géologique de France, 11(2): 250-256, pl. 2.

Murray, A. 1845. no specific title, but a progress report on “a geological examination of the district lying in a general line between Georgian Bay on Lake Huron, and the lower extremity of Lake Erie”. Geological Survey of Canada, Report of Progress for 1843, p.51-91.

Murray, A. 1850. no specific title, but a progress report on “the examination of the shores, islands and rivers of Lake Huron”. Geological Survey of Canada, Report of Progress for 1848-49, p.7-46.

Murray, A. 1852. no specific title, but a progress report on “the examination of the western portion of the Province, comprising the great Peninsula, bounded by Lakes Huron, St. Clair and Erie”. Geological Survey of Canada, Report of Progress for 1850-51, p.61-98.

Nettelroth, H. 1889. Kentucky fossil shells; A monograph of the fossil shells of the Silurian and Devonian rocks of Kentucky. Kentucky Geological Survey. 245pp., 36 pl.

Norris, A. W. 1993. Brachiopods from the Lower Shale Member of the Williams Island Formation (Middle Devonian) of the Hudson Platform, Northern Ontario and Southern district of Keewatin. Geological Survey of Canada, Bulletin 460, 113pp., 16pl.

Oehlert, D. P. 1887a. Appendice sur les brachiopodes. In: P., Fischer (ed.), Manuel de Conchyliologie et de Paléontologie conchyliologique ou Histoire naturelle des Mollusques vivants et fossiles, vol. 4, part 11. Librairie F. Savy. Paris. p. 1189–1334, fig. 892–1138, pl. 15.

Oehlert, D. P. 1887b. Molluscodes: Brachiopodes. L'Annuaire Géologique Universel, 3: 162–180.

Oehlert, D. P. 1888. Descriptions de quelques espèces dévoniennes du Département de la Mayenne. Bulletin de la Sociétéd'études Scientifiques d'Angers(new series)XVII^{e}Année, 1887: 65-120, pl. 6-10.

Oehlert, D. P. 1890. Note sur différents groupes établis dans le genre *Orthis* et en particulier sur *Rhipidomella* Oehlert (=*Rhipidomys* Oehlert, olim). Journal de Conchyliologie, 30:366–374.

Oleneva, N.V. 1998. New species of Middle and Upper Devonian brachiopods from the Mongolian Altai. Paleontological Journal, 32(2): 147-153.

Oliver, W. A. J. 1981. The Middle Devonian rugose coral *Prismatophyllum conjunctum* (Davis) and the age of the "Columbus" Limestone at Ingersoll, Ontario. Geological Society of America Bulletin, 92(1): 873-877.

Öpik, A. A. 1934. Über Klitamboniten. Universitatis Tartuensis (Dorpatensis) Acta et Commentationes (series A), 26(5): 1–239, 48 pl.

d'Orbigny, A. 1847. Considérations zoologiques et géologiques sur les Brachiopodes ou Palliobranches. Comptes Rendus Hebdomadaires des Séances de l'Académie des Sciences, 25:193–195, 266–269.

Orr, R. W. 1971. Conodonts from Middle Devonian strata of the Michigan Basin. Department of Natural Resources, State of Indiana, Geological Survey Bulletin 45. 128pp.

Owen, D. D. 1852. Description of new and imperfectly known genera and species of organic remains, collected during the geological surveys of Wisconsin, Iowa and Minnesota. In: report of a geological survey of Wisconsin, Iowa and Minnesota and incidentally of a portion of Nebraska territory, p. 573-578, 27 pl.

Peterson, R. M. 1964. Ostracodes of the Superfamilies Quasillitacea and Kloedenellacea from the Middle Devonian Strata of Michigan, Ohio, New York, and Ontario. Journal of Paleontology, 38(5): 836-865.

Phillips, J. 1841. Figures and descriptions of the Palaeozoic fossils of Cornwall, Devon, and west Somerset. Geological Survey of Great Britain, Memoirs, 1: 1-231, 60 pl.

Pitrat, C. W., and Rogers, F. S. 1978. *Spinocyrtia* and its epibionts in the Traverse Group (Devonian) of Michigan. Journal of Paleontology, 52(6): 1315-1324, 8 text-figs.

Popov, L. E., Bassett, M. G., Holmer, L. E., and Laurie, J. R. 1993. Phylogenetic analysis of higher taxa of Brachiopoda. Lethaia, 26:1–5.

Prosser, C. S., and Kindle, E. M. 1913. Systematic paleontology of the Middle Devonian deposits of Maryland. Maryland Geological Survey of Middle and Upper Devonian, p. 122-335, pl. 7-44.

Quinlan, G. 1987. Models of subsidence mechanism in intracratonic basins, and their applicability to North American examples. In: C., Beaumont, and A. J., Tankard (eds.), Sedimentary basins and basin forming mechanisms. Canadian Society of Petroleum Geologists, Memoir 12: 463-481.

Quinlan, G. M., and Beaumont, C. 1984. Appalachian thrusting, lithospheric flexure, and the Paleozoic stratigraphy of the Eastern Interior of North America. Canadian

Journal of Earth Sciences. 21: 973-996.

Raup, D., and Crick, R. E. 1979. Measurement of faunal similarity in paleontology. Journal of Paleontology, 53: 1213-1227.

Raymond, P. E. 1911. The Brachiopoda and Ostracoda of the Chazyan. Annals of the Carnegie Museum, 7(2):215–259.

Richard, L. V. 1975. Correlation of the Silurian and Devonian rocks in New York state. New York state Museum and Science Service, Map and Chart series Number 24. State University New York, 16pp.

Rickard L. V. 1984. Correlation of the subsurface Lower and Middle Devonian of the Lake Erie region. Geological Society of America Bulletin, 95: 814-828.

Rode, A. L. S. 2005. Systematic revision of the Middle and Late Devonian brachiopods *Schizophoria* (*Schizophoria*) and '*Schuchertella*' from North America. Journal of Systematic Palaeontology, 3(2): 133-167.

Rodgers, J. 1967. Chronology of tectonic movement in the Appalachian region of eastern North America. American Journal of Science, 265: 408-427.

Rodgers, J. 1970. Tectonics of the Appalachians. John Wiley and Sons, Inc., New York. 271pp.

Rogers, H. D. 1858. Geology of Pennsylvania: A government survey. With a general view of the geology of the U.S., Essays on the Coral Formation and its fossils, and a description of the coral-fields of North America and Great Britain, 2: 1-1045, 52 pl.

Rowell, A. J. (ed.) 1965. Inarticulata. In: R. C. Moore (ed.), Treatise on Invertebrate Paleontology, Pt. H, Brachiopoda, vol. 1. Geological Society of America & University of Kansas Press, Lawrence. p. H260-H297, fig. 158-187.

Ryder, R. T. 1992. Stratigraphic framework of Cambrian and Ordovician rocks in the central Appalachian basin from Lake County, Ohio, to Juniata County, Pennsylvania. U.S. Geological Survey Miscellaneous Investigations. Series Map 1-2200.

Ryder, R. T., Burruss, R. C., Hatch, J. R. 1998. Black shale source rocks and oil generation in the Cambrian and Ordovician of the central Appalachian basin, USA. American Association of Petroleum Geology. 82: 412-441.

Ryder, R. T., Harris, A. G., and Repetski, J. E. 1992. Stratigraphic framework of Cambrian and Ordovician rocks in the central Appalachian basin from Medina County, Ohio, through southwestern and south-central Pennsylvania to Hampshire County, West Virginia. Bulletin of U.S. Geological Survey. 1839:K1-K32.

Rzhonsnitskaia, M. A. 1956. Nadsemeistvo Pentameracea M'Coy, 1844. In: L. D., Kiparisova, V. P., Markovskii, and G. P., Radchenko (eds.), Materialy po Paleontologii, Novye Semeistva i Rody. Vsesoiuznyi Nauchno-Issledovatel'skii Geologicheskii Institut (VSEGEI) (new series), 12: 49–50.

Rzhonsnitskaia, M. A. 1960. Order Atrypida. In: T. G., Sarytcheva (asst. ed.), Mshanki, Brakhiopody [Bryozoa, Brachiopoda], Y. A., Orlov (ed.), Osnovy Paleontologii, vol. 7. Akademia Nauk SSSR. Moscow. p. 257–264, pl. 53–56.

Sanford, B. V. 1967. Devonian of Ontario and Michigan. In: D. H., Oswald (ed.), International Symposium on the Devonian Calgary. Alberta Society of Petroleum Geologist, 1: 973-999.

Sapelnikov, V. P. 1973. Novye taksonomicheskie gruppy v otriade Pentamerida (Brakhiopody) [New taxonomic groups in the order Pentamerida (brachiopods)]. In:

Ezhegodnik, 1972 Institut Geologii i Geokhimii, Uralskii Nauchnyi Tsentr. Akademia Nauk SSSR. Sverdlovsk. p. 39–41.

Sarytcheva, T. G., and Sokolskaya, A. N. 1959. O klassifikatsin lozhnoporistykh brakhiopod [On the classification of pseudopunctate brachiopods]. Akademiia Nauk SSSR, Doklady (Moscow), 125(1):181–184.

Savage, N. M. 1969. New spiriferid brachiopods from the Lower Devonian of New South Wales. Palaeontology, 12(3): 472-487, Pl. 89-92.

Savage, N. M. 1970. New Atrypid brachiopods from the Lower Devonian of New South Wales. Journal of Paleontology, 44(4): 655-667, Pl. 101-103.

Savage, N. M. 1971. Brachiopods from the Lower Devonian Mandagery Park Formation, New South Wales. Palaeontology, 14(3): 387-422, Pl. 69-74.

Savage, N. M. 1981. A reassessment of the age of some Paleozoic brachiopods from southeastern Alaska. Journal of Paleontology, 55(2): 353-369, 4 pl.

Savage, N. M. 1996. Classification of Paleozoic rhynchonellid brachiopods. In: P., Copper, and J., Jin (eds.), Brachiopods. A. A. Balkema. Rotterdam. p. 249–260.

Savage, T. E. 1923. Comparison of the Devonian rocks of Illinois and Missouri. Journal of Geology, 33(5): 550-558.

Savarese, M., Gray, L. M., and Brett, C. E. 1986. Faunal and lithologic cyclicity in the Centerfield Member (Middle Devonian: Hamilton Group) of Western New York: a reinterpretation of depositional history. New York State Museum and science service Bulletin, 457: 32-56.

Schlotheim, E. F. 1822. Nachtragen zur Petrefactenkunde. Gotha: Bekker. 100pp., 21 pl.

Schroter, J. S. 1777. Abhandlungen über verschiedene Gegenstande der Naturgeschechte: Theil 2 9th Ablandlung von den Versteinter Anomiten und Terebratuliten, Besonders von den Terebratuliten im Bergischen und in der Eifel. 462pp., 5pl.

Schuchert, C. 1897. A synopsis of American fossil brachiopoda, including bibliography and synonymy. United States Geological Survey Bulletin, 87: 1-464.

Schuchert, C. 1913a. Class 2. Brachiopoda. In: K. A. von, Zittel, Text-book of Palaeontology, vol. 1, part 1, 2nd ed., translated and edited by C. R., Eastman. London: MacMillan & Co., Ltd. p. 355–420.

Schuchert, C. 1913b. Class Brachiopoda. The Lower Devonian deposits of Maryland. Maryland Geological Survey, Baltimore, p. 290–449, pl. 53–74.

Schuchert, C. 1929. Classification of brachiopod genera, fossils and recent. In: C., Schuchert, and C. M., LeVene (eds.), Brachiopoda (Generum et Genotyporum Index et Bibliographia). Fossilium Catalogus I: Animalia, vol. 42. W. Junk. Berlin. p. 10–25.

Schuchert, C., and Cooper, G. A. 1931. Synopsis of the brachiopod genera of the suborders Orthoidea and Pentameroidea, with notes on the Telotremata. American Journal of Science (series 5), 22: 241–255.

Schuchert, C., and Cooper, G. A. 1932. Brachiopod genera of the suborders Orthoidea and Pentameroidea. Memoirs of the Peabody Museum of Natural History, 4(1):1-270, pl. A, 1–29.

Shimer, H. W., and Grabau, A. W. 1902. The Hamilton Group of Thedford, Ontario.

Bulletin of the Geological Society of America, 13: 149-186.
Shimer, H. W., and Shrock, R. R. 1944. Index fossils of North America. New York: John Wiley and Sons, Inc.. 837pp., 303pl.
Simpson, G. G. 1943. Mammals and the nature of continents. American Journal of Science, 241: 1-31.
Sinclair, H. D. 1997. Tectonostratigraphic model for underfilled peripheral basins: an alpine perspective. Geological Society of America Bulletin, 109:324-346.
Slattery, W. 1995. Depositional cycles and sequence stratigraphy of the Upper Hamilton Group (Givetian) of Pennsylvania and New York, Eustatically driven? Northeastern Geology and Environmental Sciences. 17(4): 422-430.
Southworth, C. 1967. A guide to the fossil-bearing areas of Arkona, Thedford and Vicinity. Published by Lambton County Historical Society, Printed by Petrolia Advertiser-Topic, 19 pp.
Stainbrook, M. A. 1942. Brachiopoda of the Cedar Valley beds of Iowa: Inarticulata, Rhynchonellacea and Rostrospiracea. Journal of Paleontology, 16(5): 604-619, pl. 88-89.
Stainbrook, M. A. 1945. Brachiopoda of the Independence Shale of Iowa. Geological Society of America, Memoir 14: 1–74, 6 pl.
Stauffer, C. R. 1915. The Devonian of southwestern Ontario. Geological Survey of Canada, 34: 1-341, pl. 1-20.
Stauffer, C. R. 1916. The relationships of the Olentangy Shale and associated Devonian deposits of Northern Ohio. Journal of Geology, 24(5): 476-487.
Stewart, G. A. 1927. Fauna of the Silica Shale of Lucas County. Bulletin of Geological Survey of Ohio, 32:1-76, 5pl.
Ver Straeten, C. A. 2004. K-bentonites, volcanic ash preservation, and implications for Early to Middle Devonian volcanism in the Acadian orogen, eastern North America. Geological Society of America Bulletin. 116(3/4): 474-489.
Stumm, E. C. 1942. Fauna and stratigraphic relations of the Prout limestone and Plum Brook shale of northern Ohio. Journal of Paleontology, 16(5): 549-563, pl. 80-84.
Stumm, E. C., 1949. Three new Devonian species of *Microcyclus* from Michigan and Ontario: Journal of Paleontology, 23: 507-509.
Stumm, E. C. 1951. Check list of fossil invertebrates described from the Middle Devonian Traverse Group of Michigan. Contributions from the Museum of Paleontology, University of Michigan, 9(1): 1-44.
Stumm, E. C., 1953. Lower Middle Devonian proetid trilobites from Michigan, southwestern Ontario, and northern Ohio: Contributions from the Museum of Paleontology, University of Michigan, 11(2):11-31.
Stumm, E. C. 1956. A revision of A.W. Grabau's species of *Mucrospirifer* from the Middle Devonian Traverse Group of Michigan. Contributions from the Museum of Paleontology, University of Michigan, 13(3): 81-94.
Stumm, E. C. 1961. Addenda to the check list of fossil invertebrates described from the Traverse Group of Michigan. Contributions from the Museum of Paleontology, University of Michigan, 17(5): 149-171.
Stumm, E. C., Kellum, L. B., and Wright, J. D. 1956. The Devonian strata of the London-Sarnia area, southwestern Ontario. Michigan Geological Society-Annual

Field trip, June 9-10.
Stumm, E. C., and Wright, J. D. 1958. Check list of fossil invertebrates described from the Middle Devonian rocks of the Thedford-Arkona region of southwestern Ontario. Contributions from the Museum of Paleontology, University of Michigan, 14(7): 81-132.

Telford, P. G. 1975. Waterloo 1975 field excursions guidebook. Geological Association of Canada. 29pp.

Telford, P. G.; and Johnson, M. D. 1984. Paleozoic stratigraphy of southwestern Ontario. Geological Association of Canada-Mineralogical Association of Canada Joint Annual Meeting, Field Trip Guidebook no.1. 45pp.

Termier, H., and Termier, G. 1949. Essai sur l'évolution des spiriféridés. Division des Mines et de la Géologie, Service Géologique, Notes et Mémoires, Notes du Service Géologique (Tome 2), 74B: 85–112.

Thomas, W.A. 1977. Evolution of Appalachian and Ouachita salients and recesses from reentrants and promontories in the continental margin. American Journal of Science, 277:1233–1278.

Thomson, J. A. 1926. A revision of the subfamilies of the Terebratulidae (Brachiopoda). Annals and Magazine of Natural History (series 9), 18(107): 523–530.

Tillman, J. R. 1964. Variation in species of *Mucrospirifer* from middle Devonian rocks of Michigan, Ontario, and Ohio. Journal of Paleontology, 38(5): 952-964.

Tsujita, C. J., Tetreault, D. K., and Jin, J. 2001. Middle and Upper Devonian strata of southwestern Ontario. Canadian Paleontology Conference 2001, Field Trip Guidebook, no. 9. Geological Association of Canada, Paleontology Division 2001. 43 pp., 7pl.

Tyler, J. H. 1969. Gastropods from the Middle Devonian Four Mile Dam Limestone (Hamilton) of Michigan. Journal of Paleontology, 39(3): 341-349.

Uyeno, T.T., Telford, P.G., and Sanford, B.V. 1982. Devonian conodonts and stratigraphy of southwestern Ontario; Geological Survey of Canada Bulletin No. 332, 55pp.

Vanuxem, L. 1842. Geology of New York, part 3, comprising the survey of the third geological district. Natural History of New York, 4(3): 1-306, 80 fig.

Waagen, W. 1883. Salt Range fossils, vol. I, part 4. *Productus* Limestone fossils, Brachiopoda. Memoirs of the Geological Survey of India, Palaeontologia Indica (series 13), 4(2): 391–546, pl. 29–49.

Waagen, W. 1884. Salt Range fossils, vol. I, part 4. *Productus* Limestone fossils, Brachiopoda. Memoirs of the Geological Survey of India, Palaeontologia Indica, 13(3–4): 547–728, pl. 50–81.

Waagen, W. 1885. Salt Range fossils, vol. I, part 4. *Productus* Limestone fossils, Brachiopoda. Memoirs of the Geological Survey of India, Palaeontologia Indica, 13 (5): 729–770, pl. 82–86.

Walcott, C. D. 1884. Paleontology of the Eureka District. United States Geological Survey Monographs, 8: 1-298, 24pl.

Ward, J. H. 1963. Hierarchical grouping to optimize an objective function. Journal of the American Statistical Association, 58: 236-244.

Webster, C. L. 1921. Notes on the genus *Atrypa* with descriptions of new species. Amer.

Midl. Natur, 7: 13-20.

Welch, D. E. 1991. Geographical variation and evolution in the Middle Devonian brachiopod, *Mucrospirifer*. Ph.D. Dissertation, Department of Geological Sciences, Virginia Polytechnic Institute and State University. 185pp.

Wells, J. W. 1956. The Ammonoids Koenenites and Beloceras in the Upper Devonian of New York. Journal of Paleontology, 30(3): 749-751.

White, C.A. 1862. Description of new species of fossils from the Devonian and Carboniferous rocks of the Mississippi Valley. Boston Society of Natural History Proceedings, 9: 8-33, 5fig.

Whiteaves, J. F., 1889. On some fossils from the Hamilton Formation of Ontario, with a list of the species at present known from that formation and province. Geological and Natural History Survey of Canada, Contributions to Canadian Paleontology, 1(2): 91-125.

Whiteaves, J. F. 1891. The fossils of the Devonian rocks of the Mackenzie River basin. Geological Survey of Canada, Contributions to Canadian Palaeontology, 1(3): 197-253, 6 pl.

Whiteaves, J. F. 1892. The fossils of the Devonian rocks of the islands, shores, or immediate vicinity of Lakes Manitoba and Winnepegosis. Geological Survey of Canada, Contributions to Canadian Palaeontology, 1(4): 255-359, pl. 33-47.

Whiteaves, J. F. 1898. On some additional or imperfectly understood fossils from the Hamilton Formation of Ontario, with a revised list of the species therefrom. Contributions to Canadian Palaeontology, Geological and Natural History Survey of Canada, 1(7): 361-436.

Williams, A., Carlson, S. J., Brunton, C. H. C., Holmer, L. E., and Popov, L. E. 1996. A supra-ordinal classification of the Brachiopoda. Philosophical Transactions of the Royal Society of London (series B), 351:1171–1193.

Williams, H. S. 1890. The cuboides zone and its fauna; A discussion of methods of correlation. Bulletin of Geological Society of America, 1: 481-500, 2pl.

Winchell, A. 1862. Descriptions of fossils from the Marshall and Huron groups of Michigan. Academy of Natural Sciences of Philadelphia, Proceedings, 14(2): 405-430.

Winder, C. G., and Sanford, B. V. 1972. Stratigraphy and paleontology of the Paleozoic rocks of southern Ontario. 24th International Geological Congress, Montreal, Excursion A45-C45. 74pp.

Wright, J. D. 1975. Two species of a new brachiopod genus from Middle Devonian beds of Ontario and Michigan. Contributions from the Museum of Paleontology, University of Michigan, 24(16): 171-180, 4pl.

Wright, J. D., and Wright, E. P. 1961. A study of the Middle Devonian Widder Formation of southwestern Ontario. Contributions from the Museum of Paleontology, University of Michigan, 16(5): 287-300. 1pl.

Wright, J. D., and Wright, E. P. 1963. The Middle Devonian Ipperwash Limestone of southwestern Ontario and two new brachiopods therefrom. Contributions from the Museum of Paleontology, University of Michigan, 18(7): 117-134, 3pl.

Wylie, A.S., and Huntoon, J.E., 2003. Log-curve amplitude slicing: visualization of log data and depositional trends in the Middle Devonian Traverse Group, Michigan

Basin, United States, Bulletin of the American Association of Petroleum Geologists, 87(4): 581-608.

Zhuravlev, A. V., Sokiran, E. V., Evdokimova, I. O., Dorofeeva, L. A., Rusetskaya, G. A., and Malkowski, K. 2006. Faunal and facies changes at the Early–Middle Frasnian boundary in the north–western East European Platform. Acta Palaeontologica Polonica, 51 (4): 747–758.

Appendix A

Faunal list and abbreviations used in Figure 3-2:

1. SC: Ledyard Member, Ludlowville Formation, Hamilton Group, Spring Creek, near Alden, western New York (Fisher, 1951); *Ambocoelia*, *Athyris*, *Brachyspirifer*, *Chonetes*, *Devonochonetes*, *Leiorhynchus*, *Mucrospirifer*, *Nucleospira*, *Productella*, *Schuchertella* (Now *Floweria*), *Spinocyrtia*, *Strophalosia* (Now *Productella*).

2. LGF: Ledyard Member, Ludlowville Formation, Hamilton Group, from the Lake Erie shore eastward to the Genesee Valley, and Finger Lakes region (McCollum, 1986); *Ambocoelia*, *Athyris*, *Craniops*, *Devonochonetes*, *Leiorhynchus*, *Lingula*, *Longispina*, *Mucrospirifer*, *Orbiculoidea*, *Protoleptostrophia*, *Rhipidomella*, *Schuchertella* (Now *Floweria*), *Spinulicosta* (Now *Productella*), *Tropidoleptus* (Now *Castellaroina*), *Truncalosia*.

3. RC: Darien Center Submember, the base of Wanakah Member, Ludlowville Formation, Hamilton Group, Rush Creek, western New York (Miller, 1986); *Ambocoelia*, *Athyris*, *Camarotoechia*, *Cryptonella*, *Cyrtina*, *Devonochonetes*, *Douvillina*, *Elita*, *Longispina*, *Mediospirifer*, *Mucrospirifer*, *Nucleospira*, *Pholidostrophia*, *Protoleptostrophia*, *Rhipidomella*, *Schuchertella* (Now *Floweria*), *Spinocyrtia*, *Spinulicosta* (Now *Productella*), *Tropidoleptus* (Now *Castellaroina*), *Truncalosia*.

4. LCA: Centerfield Member, Ludlowville Formation, Hamilton Group, Livingston

County, western New York (Savarese, et al., 1986); *Ambocoelia*, *Athyris*, *Cyrtina*, *Devonochonetes*, *Douvillina*, *Echinocoelia*, *Elita*, *Leiorhynchus*, *Longispina*, *Mediospirifer*, *Meristella*, *Mucrospirifer*, *Nucleospira*, *Parazyga*, *Pholidostrophia*, *Productella*, *Protoleptostrophia*, *Pseudoatrypa*, *Rhipidomella*.

5-1. TBA: Bell Shale Formation, Traverse Group, Thunder Bay region, comprising the northeastern part of Alpena County and the southwestern part of Presque Isle County, Michigan (Stumm, 1951); *Atrypa*, *Chonetes* (Now *Devonochonetes*), *Cryptonella*, *Leiorhynchus*, *Leptostrophia*, *Mucrospirifer*, *Pholidostrophia*, *Spinocyrtia*, *Stropheodonta* (Now *Strophodonta*).

5-1. TBB: Ferron Point Formation, Traverse Group, Thunder Bay region, comprising the northeastern part of Alpena County and the southwestern part of Presque Isle County, Michigan (Stumm, 1951); *Athyris*, *Atrypa*, *Chonetes*, *Cranaena*, *Cyrtina*, *Meristella*, *Mucrospirifer*, *Pentamerella*, *Schizophoria*, *Spinocyrtia*, *Stropheodonta* (Now *Strophodonta*).

5-1. TBC: Genshaw Formation, Traverse Group, Thunder Bay region, comprising the northeastern part of Alpena County and the southwestern part of Presque Isle County, Michigan (Stumm, 1951); *Athyris*, *Atrypa*, *Brachyspirifer*, *Chonetes*, *Cranaena*, *Cyrtina*, *Gypidula*, *Meristella*, *Mucrospirifer*, *Pentamerella*, *Petrocrania*, *Pholidostrophia*, *Productella*, *Protoleptostrophia*, *Schizophoria*, *Spinocyrtia*, "*Spirifer*", *Stropheodonta* (Now *Strophodonta*).

5-1. TBD: Newton Creek Limestone, Traverse Group, Thunder Bay region, comprising the northeastern part of Alpena County and the southwestern part of Presque Isle County, Michigan (Stumm, 1951); *Camarophoria* (Now *Stenoscisma*), *Charionella*, *Cranaena*, *Pentamerella*.

5-1. TBE: Alpena Limestone, Traverse Group, Thunder Bay region, comprising the northeastern part of Alpena County and the southwestern part of Presque Isle County, Michigan (Stumm, 1951); *Atrypa*, *Chonetes*, *Cyrtina*, *Hercostrophia*, *Longispina*, *Mucrospirifer*, *Pholidostrophia*, *Spinocyrtia*, *Stropheodonta* (Now *Strophodonta*).

5-1. TBF: Four Mile Dam Formation, Traverse Group, Thunder Bay region, comprising the northeastern part of Alpena County and the southwestern part of Presque Isle County, Michigan (Stumm, 1951); *Atrypa*, *Brachyspirifer*, *Callipleura*, *Camarospira*, *Camerophoria* (Now *Stenoscisma*), *Elytha* (Now *Elita*), *Fimbrispirifer*, *Megastrophia*, *Mucrospirifer*, *Parazyga*, *Pentamerella*, *Spinocyrtia*, *Trematospira*.

5-1. TBG: Norway Point Formation, Traverse Group, Thunder Bay region, comprising the northeastern part of Alpena County and the southwestern part of Presque Isle County, Michigan (Stumm, 1951); *Athyris*, *Atrypa*, *Camarotoechia*, *Chonetes*, *Cranaena*, *Cryptonella*, *Cyrtina*, *Megastrophia*, *Mucrospirifer*, *Pentamerella*, *Pholidostrophia*, *Spinocyrtia*, *Stropheodonta* (Now *Strophodonta*).

5-1. TBH: Potter Farm Formation, Traverse Group, Thunder Bay region, comprising the northeastern part of Alpena County and the southwestern part of Presque Isle

County, Michigan (Stumm, 1951); *Cranaena*, *Mucrospirifer*.

5-1. TBI: Thunder Bay Formation, Traverse Group, Thunder Bay region, comprising the northeastern part of Alpena County and the southwestern part of Presque Isle County, Michigan (Stumm, 1951); *Athyris*, *Atrypa*, *Camarotoechia*, *Chonetes*, *Cranaena*, *Cyrtina*, *Meristella*, *Mucrospirifer*, *Pentamerella*.

5-2. AOA: Ferron Point Formation, Traverse Group, Afton-Onaway region in western Presque Isle County and eastern Cheboygan County, Michigan (Stumm, 1951); *Chonetes* (Now *Devonochonetes*), *Mucrospirifer*, *Pentamerella*.

5-2. AOB: Genshaw Formation, Traverse Group, Afton-Onaway region in western Presque Isle County and eastern Cheboygan County, Michigan (Stumm, 1951); *Chonetes* (Now *Devonochonetes*), *Cyrtina*, *Mucrospirifer*, *Pentamerella*.

5-2. AOC: Gravel Point Formation, Traverse Group, Afton-Onaway region in western Presque Isle County and eastern Cheboygan County, Michigan (Stumm, 1951); *Atrypa*, *Cranaena*, *Longispina, Mucrospirifer*, *Pentamerella*, *Pholidostrophia*.

5-2. AOD: Beebe School Formation, Traverse Group, Afton-Onaway region in western Presque Isle County and eastern Cheboygan County, Michigan (Stumm, 1951); *Cranaena*, *Cyrtina*, *Mucrospirifer*, *Productella*, *Stropheodonta* (Now *Strophodonta*).

5-3. LTBA: Gravel Point Formation, Traverse Group, Little Traverse Bay region in northwestern Charlevoix County and southern Emmet County, Michigan (Stumm, 1951); *Athyris*, *Atrypa*, *Cranaena*, *Cryptonella*, *Cyrtina*, *Douvillina*, *Elytha* (Now

Elita), *Gypidula*, *Leptalosia*, *Longispina*, *Megastrophia*, *Mucrospirifer*, *Pentamerella*, *Pholidostrophia*, *Schuchertella* (Now *Floweria*), *Spinocyrtia*, "*Spirifer*", *Stropheodonta* (Now *Strophodonta*), *Stuartella* (Now *Hamburgia*).

5-3. LTBB: Charlevoix Limestone, Traverse Group, Little Traverse Bay region in northwestern Charlevoix County and southern Emmet County, Michigan (Stumm, 1951); *Athyris*, *Atrypa*, *Chonetes* (Now *Devonochonetes*); *Cyrtina*, *Elytha* (Now *Elita*), *Gypidula*, *Mucrospirifer*, *Pentamerella*, *Productella*, *Spinocyrtia*, "*Spirifer*", *Stropheodonta* (Now *Strophodonta*).

5-3. LTBC: Middle Petoskey Limestone, Traverse Group, Little Traverse Bay region in northwestern Charlevoix County and southern Emmet County, Michigan (Stumm, 1951); *Atrypa*

5-3. LTBD: Upper Petoskey Limestone, Traverse Group, Little Traverse Bay region in northwestern Charlevoix County and southern Emmet County, Michigan (Stumm, 1951); *Leptaena*, *Pentamerella*, *Pugnoides*, "*Reticularia*", *Schizophoria.*

6. OC: Delphi Station Member, Skaneateles Formation, Hamilton Group, central New York, U.S. Route 20, 1.6 km east of Pompey Center, Onondaga County, New York (Brower, et al., 1987); *Ambocoelia*, *Athyris*, *Devonochonetes*, *Leiorhynchus*, *Mucrospirifer*, *Protoleptostrophia*, *Schuchertella* (Now *Floweria*), *Spinulicosta* (Now *Productella*).

7. LCB: The upper part of the Levanna Member, Skaneateles Formation, Hamilton

Group, waterfalls and banks of Browns Creek, 0.1 to 0.3 miles west of trestle of Genesee and Wyoming Railroad, York, Livingston County, New York (Brett et al., 1991); *Ambocoelia*, *Devonochonetes*, *Echinocoelia*, *Eumetabolotoechia*, *Lingula*, *Longispina*, *Mucrospirifer*, *Orbiculoidea*, *Pholidops* (Now *Craniops*), *Schuchertella* (Now *Floweria*).

8. SCA. The upper part of Levanna Member, Skaneateles Formation, Hamilton Group, quarry (town dump) immediately south of Poorman Road, 0.3 miles west of Fayette, Seneca County, New York (Brett et al., 1991); *Camarotoechia*?, *Devonochonetes*, *Echinocoelia*, *Eumetabolotoechia*, *Longispina*, *Mucrospirifer*, *Orbiculoidea*.

9. ECA. The lower part of the Ledyard Member, Ludlowville Formation, Hamilton Group, low banks of Buffalo Creek between Bowen and Girdle Roads, Elma, Erie County, New York (Brett et al. 1991); *Ambocoelia*, *Camarotoechia*?, *Devonochonetes*, *Eumetabolotoechia*, *Lingula*, *Longispina*, *Mucrospirifer*, *Orbiculoidea*, *Schuchertella* (Now *Floweria*).

10. SCB: The middle part of the Windom Shale Member, Moscow Formation, Hamilton Group, creek banks along Bloomer and Mack Creeks, near the east edge of the quadrangle, 2 miles east of Hayts Corners, Seneca County, N. Y. (Brett et al., 1991); *Allanella*, *Ambocoelia*?, *Ambocoelia*, *Devonochonetes*, *Eumetabolotoechia*, *Lingula*, *Longispina*, *Mucrospirifer*, *Orbiculoidea*, *Schuchertella* (Now *Floweria*).

11. GCA: Ledyard Member, Ludlowville Formation, Hamilton Group, East-facing

shale pit bank on Bethany Center Road, 3.0 km north of Bethany Center, Genesee County, New York (Brett et al., 1991); *Ambocoelia*, *Cyrtina*, *Devonochonetes*, *Eumetabolotoechia*, *Lingula*?, *Longispina*, *Mucrospirifer*, *Protoleptostrophia*, *Pseudoatrypa*.

12. LCC: Kashong and Windom Members, Moscow Formation, Hamilton Group, banks of Fall Brook 0.4 miles east of (upstream from) New York, Route 20A-39 overpass, 1.4 miles south of Geneseo, Livingston County, New York (Brett et al., 1991); *Ambocoelia*, *Devonochonetes*, *Longispina*, *Mucrospirifer*, *Orbiculoidea*, *Pholidops* (Now *Craniops*), *Pseudoatrypa*, *Schuchertella* (Now *Floweria*).

13. GCB: Ledyard and Wanakah Members, Ludlowville Formation, Hamilton Group, spoil heaps along banks and railroad cut along Delaware, Lackawanna, and Western railroad tracks near Francis Road overpass, 2.5 km east of Alexander, Genesee County, New York (Brett et al., 1991); *Ambocoelia*, *Camarotoechia*, *Chonetes*, *Cyrtina*, *Devonochonetes*, *Eumetabolotoechia*, *Mucrospirifer*, *Orbiculoidea*, *Rhipidomella*, *Schuchertella* (Now *Floweria*), *Tropidoleptus* (Now *Castellaroina*).

14. LCD: Ledyard and Wanakah Members, Ludlowville Formation, Hamilton Group, shale banks of Bidwell Creek (tributary of salt Creek), 1.5 km northeast of Retsof Corners in Retsof, Livingston County, New York (Brett et al., 1991); *Ambocoelia*, *Chonetes*, *Devonochonetes*, *Mucrospirifer*, *Orbiculoidea*, *Tropidoleptus* (Now *Castellaroina*).

15. LCE: Kashong and Windom Members, Moscow Formation, Hamilton Group, high bank of Little Beards Creek 0.6 miles northeast of junction of New York Routes 36 and 20A-39 in Leicester, Livingston County, New York (Brett et al., 1991); *Allanella*?, *Ambocoelia*, *Cyrtina*, *Mucrospirifer*, *Rhipidomella*, *Spinocyrtia*, *Tropidoleptus* (Now *Castellaroina*).

16. ATIA. Upper Arkona Shale Formation, Arkona-Thedford-Ipperwash area, southwestern Ontario (this thesis); *Ambocoelia*, *Athyris*, *Cyrtina*, *Devonalosia*, *Devonochonetes*, *Floweria*, *Leiorhynchus*, *Mucrospirifer*, *Productella*, *Spinocyrtia*, *Strophodonta*.

16. ATIB. Hungry Hollow Member, Widder Formation, Arkona-Thedford-Ipperwash area, southwestern Ontario (this thesis); *Ambocoelia*, *Athyris*, *Atrypa*, *Callipleura*, *Camarotoechia*, *Charionella*, *Cranaena*, *Cryptonella*, *Cyrtina*, *Devonochonetes*, *Douvillina*, *Elita*, *Floweria*, *Leiorhynchus*, *Lingula* ?, *Mediospirifer* ?, *Megastrophia*, *Mucrospirifer*, *Nucleospira*, *Orbiculoidea*, *Parazyga*, *Pentagonia*, *Pentamerella*, *Petrocrania*, *Philhedra*, *Pholidostrophia*, *Protoleptostrophia*, *Pseudoatrypa*, *Rhipidomella*, *Spinocyrtia*, *Stenoscisma*, *Strophodonta*.

16. ATIC. Thedford Member, Widder Formation, Arkona-Thedford-Ipperwash area, southwestern Ontario (this thesis); *Ambocoelia*, *Athyris*, *Cyrtina*, *Devonochonetes*, *Leiorhynchus*, *Mucrospirifer*, *Pholidostrophia*, *Protoleptostrophia*.

16. ATID. Rock Glen Submb., Petrolia Member, Widder Formation,

Arkona-Thedford-Ipperwash area, southwestern Ontario (this thesis); *Athyris*, *Cyrtina*, *Devonochonetes*, *Floweria*, *Leiorhynchus*, *Megastrophia*, *Mucrospirifer*, *Pholidostrophia*, *Protoleptostrophia*, *Strophodonta*.

16. ATIE: Golden Creek Submb., Petrolia Member, Widder Formation, Arkona-Thedford-Ipperwash area, southwestern Ontario (this thesis); *Athyris*, *Atrypa*, *Cyrtina*, *Devonochonetes*, *Mucrospirifer*, *Spinocyrtia*.

16. ATIF: Stony Point submember, Petrolia Member, Widder Formation, Arkona-Thedford-Ipperwash area, southwestern Ontario (this thesis); *Atrypa*, *Cyrtina*, *Megastrophia*, *Mucrospirifer*, *Protoleptostrophia*, *Rhipidomella*, *Spinocyrtia*.

16. ATIG: Ipperwash Limestone (unnamed formation), Arkona-Thedford-Ipperwash area, southwestern Ontario (this thesis); *Athyris*, *Atrypa*, *Cyrtina*, *Megastrophia*, *Mucrospirifer*, *Protoleptostrophia*, *Pseudoatrypa*, *Rhipidomella*, *Spinocyrtia*, *Strophodonta*.

Appendix B

Number code for the genera used in Figure 3-3:

1, *Allanella*; 2, *Ambocoelia*; 3, *Athyris*; 4, *Atrypa*; 5, *Brachyspirifer*; 6, *Callipleura*; 7, *Camarospira*; 8, *Camarotoechia*; 9, *Castellaroina*; 10, *Charionella*; 11, *Chonetes*; 12, *Cranaena*; 13, *Craniops*; 14, *Cryptonella*; 15, *Cyrtina*; 16, *Delthyris*; 17, *Devonalosia*; 18, *Devonochonetes*; 19, *Douvillina*; 20, *Echinocoelia*; 21, *Elita*; 22, *Eumetabolotoechia*; 23, *Fimbrispirifer*; 24, *Floweria*; 25, *Gypidula*; 26, *Hamburgia*; 27, *Hercostrophia*; 28, *Leiorhynchus*; 29, *Leptaena*; 30, *Leptalosia*; 31, *Leptostrophia*; 32, *Lingula*; 33, *Longispina*; 34, *Mediospirifer*; 35, *Megastrophia*; 36, *Meristella*; 37, *Mucrospirifer*; 38, *Nucleospira*; 39, *Orbiculoidea*; 40, *Parazyga*; 41, *Pentagonia*; 42, *Pentamerella*; 43, *Petrocrania*; 44, *Philhedra*; 45, *Pholidostrophia*; 46, *Productella*; 47, *Protoleptostrophia*; 48, *Pseudoatrypa*; 49, *Pugnoides*; 50, *Reticularia*; 51, *Rhipidomella*; 52, *Schizophoria*; 53, *Spinocyrtia*; 54, *Spirifer*; 55, *Stenoscisma*; 56, *Strophodonta*; 57, *Trematospira*; 58, *Truncalosia*.