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## THE WALCOTT-RUST QUARRY: MIDDLE ORDOVICIAN TRILOBITE KONSERVAT-LAGERSTÄTTEN

CARLTON E. BRETT<sup>1</sup>, THOMAS E. WHITELEY<sup>2</sup>, PETER A. ALLISON<sup>3</sup>, AND ELLIS L. YOCHELSON<sup>4</sup>

<sup>1</sup>Department of Earth and Environmental Sciences, University of Rochester, Rochester, New York 14627 (present address: Department of Geology, University of Cincinnati, Cincinnati, Ohio),

<sup>2</sup>105 White Village Drive, Rochester, New York 14625

<sup>3</sup>Department of Geology, Imperial College of Science, Technology and Medicine, London, England SW7 5BP, and

<sup>4</sup>Department of Paleobiology, National Museum of Natural History, Washington, DC 20560

**ABSTRACT**—The Walcott-Rust Quarry, at Trenton Falls, New York, has yielded a large number of well-preserved, fully articulated fossils from the lower third of the Middle Ordovician Rust Formation, Trenton Group. Along with three species of the more common trilobites from the Trenton Group, fourteen species of rare and uncommon trilobites are found within a thin package of micritic limestones and shales. The first trilobites with preserved appendages, *Ceraurus pleurexanthemus* Green, 1832 and *Flexicalymene senaria* (Conrad, 1842), were described from one layer from this quarry. Unique specimens of *Isotelus walcotti* Ulrich in Walcott, 1918, and *Sphaerocorpe robusta* Walcott, 1875, were found in the next higher bed. Re-excavation of the quarry yielded information about the taphonomy of the trilobites and stratigraphy of the trilobite layers. Nearly half of the beds surveyed ( $n = 50$ ) yield direct evidence of obrution (i.e., rapid post-mortem or live burial) of benthic organisms. Unusual anaerobic microenvironments in partially enrolled trilobites of the *Ceraurus* layer facilitated very early calcification of appendages and other soft parts.

### INTRODUCTION

MOST OF THE CLASSIC trilobite Lagerstätten (e.g., Burgess Shale, Beecher's Trilobite Bed, and Hunnsrück Shale) have received extensive recent systematic, taphonomic, and paleoenvironmental study (see Whittington and Conway-Morris, 1985 and references therein; Gould, 1989; Cisne, 1973, 1981; Allison, 1988; Briggs, Bottrel, and Raiswell, 1991; Allison and Briggs, 1991; and references therein). However, one such occurrence has largely escaped recent study: the Middle Ordovician Walcott-Rust site in central New York State. Ironically, this site was discovered and extensively collected by Charles Doolittle Walcott over one hundred years ago and some forty years before he made his more famous discovery at Burgess Pass in British Columbia.

The Walcott-Rust Quarry site provides an excellent study of obrution Lagerstätten; i.e., rapidly buried or "smothered" fossil assemblages (see Seilacher et al., 1985; Brett and Seilacher, 1991). The beds of the Walcott-Rust Quarry, now assigned to the Spillway Member of the Rust Formation, comprise a series of fine-grained limestones (calclutite to fine-grained calcarenite) and shales. Many of these thin layers yield evidence for rapid deposition as distal carbonate turbidites or storm layers. Exquisitely-preserved fossils, including at least 18 species of trilobites, occur at the bases and tops, and within a number of such beds. One layer yields specimens that are uniquely preserved with calcified appendages; these were extensively studied by the young Charles Walcott. They formed the basis of one of his earliest and still classic papers which first documented biramous limbs of trilobites.

Recently the old fossil quarry site, first excavated by Walcott and William Rust, was reopened by one of us (TEW) and extensively examined for the purpose of documenting layer by layer the fossil assemblages and the taphonomy. This paper presents an overview of the results of this collaborative study. Our objectives include: 1) documenting the precise stratigraphic levels of fossil assemblages from the quarry; 2) listing and updating the species of the trilobites from these beds; 3) documenting the sedimentology and taphonomy of trilobite-bearing beds from the quarry including orientation, alignment, position within beds, and petrology and geochemistry of soft-tissue preservation; and 4) providing an interpretation of the paleoenvironmental setting and mode of origin of these unique beds.

### HISTORICAL OVERVIEW

In 1870 Walcott, then 20 years of age, discovered a trilobite bed in Middle Ordovician limestones on a creek near the farm of William Rust, where he had recently moved (Walcott, 1918; Yochelson, 1967, 1998). The creek, named "Gray's Brook" by Walcott in his diary and on specimens, was located on the farm of a Mr. Henry Gray adjacent to the Rust farm. The Rust farm was in the Town of Russia near the western part of Herkimer County, New York, east of the Trenton Gorge on West Canada Creek. The actual quarry is about three-quarters of a mile east of Trenton High Falls in the bed of a creek, unnamed on topographic maps (Gray's brook of Walcott) (Fig. 1).

Walcott and Rust began to quarry the site to "mine" the richness of trilobites and other fossils. In 1873 Walcott and Rust sold their collections to Louis Agassiz at the Museum of Comparative Zoology (MCZ), Harvard University. In this sale Walcott came to know Louis Agassiz who convinced him to pursue a career in paleontology rather than as a professional fossil collector. In this initial meeting Walcott also mentioned that he had seen evidence of appendages and soft tissue in some of the trilobites he had collected. Agassiz recommended that he pursue this line of research.

Walcott left the area and active working of the quarry in 1876 although he returned for brief periods throughout his career. In 1877 Walcott published the first of several papers on appendages of *Ceraurus* and *Flexicalymene*. In 1879 Walcott moved to Washington, D. C. where he had obtained an appointment to the new United States Geological Survey. He also sold the fossils he had collected between 1873 and 1879 to Alexander Agassiz at the MCZ.

Rust and his friends continued to extract and sell specimens from the quarry until Rust's death in 1897. By measuring the overburden piles and understanding how a fossil quarry is mined, it is estimated that over the years 8,600 square feet were excavated.

The fossil quarry site was named the "Rust Quarry" by Delo (1934). This name, however, had been used previously for the limestone quarry excavated by Rust for his limekiln along the banks of West Canada Creek in the Steuben Limestone. Consequently, we name the fossil site the "Walcott-Rust Quarry" because of its discovery by Walcott and the collections Rust and

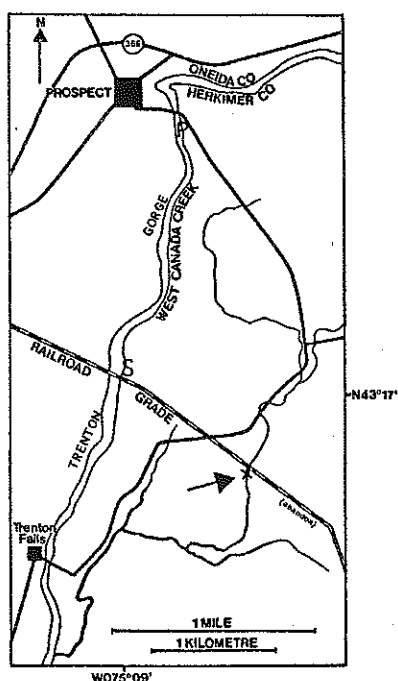
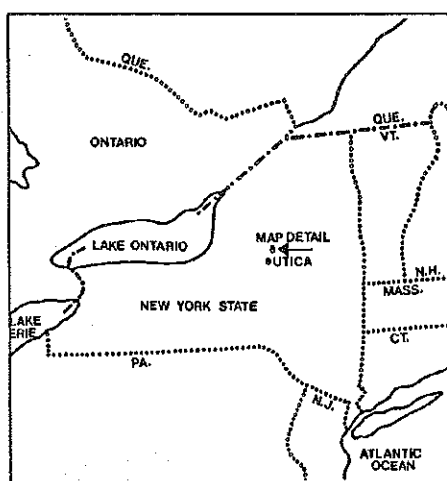


FIGURE 1—(Top) Map of New York State showing the location of Walcott-Rust Quarry area. (after Rudkin and Tripp, 1989); (Bottom) Location of exposures of the Walcott-Rust Quarry beds, Walcott-Rust Quarry site (x), the Spillway Member in the Trenton Gorge, immediately south of the Niagara-Mohawk power dam on the east side of West Canada Creek in the gorge (S), the Prospect beds on the east side of West Canada Creek immediately south of the bridge over the creek leading into Prospect, New York (P) (modified from Rudkin and Tripp, 1989).

others made which are now in the Museum of Comparative Zoology, New York State Museum and the Smithsonian Institution.

The location of this site was first published by Rudkin and Tripp (1989) in their review of *Isotelus gigas*. The site is presently on the property of Robert and Elizabeth Manning in the town of Russia, New York.

The floor of the original quarry and the limit of the current excavation was a layer beneath the *Ceraurus* layer, a bed noted for the trilobites with preserved appendages. The Walcott-Rust Quarry is the single richest and most varied source of trilobites in the New York Trenton Group limestones and perhaps in the

entire suite of New York Paleozoic rocks. The presence of so many well preserved trilobites in one location alone qualifies the beds as an exceptional trilobite site, but the beds are further distinguished as the source of the first trilobites for which appendages were definitively described.

#### MATERIALS AND METHODS

Starting in 1990, the beds along the creek and in the walls of the former quarry were systematically excavated by TEW and labeled piles of the various layers were left to weather. In this report we use the term "layer" to imply units that form discrete ledges in outcrops. These layers are separated by recessive weathering shales. We use the term "bed" for individual depositional units bounded by bedding planes. In many cases, two or more beds are amalgamated in the discretely weathering "layers."

In all, 35 layers were excavated through an interval of slightly less than 2 meters and examined in detail for trilobite material. The layers were evaluated by cutting cross-sections, polishing the section to a 600 grit, and then etching it in 5 percent hydrochloric acid for thirty seconds. These 35 layers and their shaly "interlayers" are subdivided into at least fifty beds. Many limestones initially described as "beds" are actually amalgams of two or more beds. In heavily bioturbated layers, however, the distinction between amalgamated beds is blurred.

#### STRATIGRAPHIC SETTING

The quarry beds are located within the Middle Ordovician Trenton Group. The Trenton Group is named for the Trenton Gorge at Trenton Falls along West Canada Creek about 20 km (12 miles) north of Utica, New York (Fig. 1). Only about the upper two-thirds of the Trenton Group is exposed within the gorge but this exposure is continuous from the upper part of the Sugar River Formation at the base of the exposure through the Steuben Formation at the top (Brett and Baird, in press). The name Rust (Member of the Cobourg Formation) was first assigned by Kay (1943) for the former Rust farm adjacent to the Trenton Gorge. The Rust (member) was subsequently assigned to the Denley Formation but it has recently been extensively restudied and assigned to formation status (Brett and Baird, in press) (Fig. 2). This part of the Trenton is of late Shermanian (Caradocian) age and close to the *Corynoides americanus* to lowest *Orthograptus ruedemanni* graptolite zonal boundary (Mitchell et al., 1994).

The precise biostratigraphic dating of the Rust limestones remains in question. Conodonts indicate that this interval falls within the broadly defined *Amorphognathus superbus* zone (Goldman et al., 1994). However, precise calibration with the more refined graptolite biostratigraphic zonation has proven to be difficult because the carbonate facies of the upper part of the Trenton Group, while containing some graptolites, have yielded no diagnostic species. Correlation of marker beds, including several key K-bentonite horizons from the type Trenton Falls area into adjacent sections of relatively condensed nodular limestone and dark shale to the southeast near Middleville, have provided indirect evidence that the lower portion of the Rust Limestone falls within the *Corynoides americanus* zone (Mitchell et al., 1994). At City Brook near Middleville a 3 m thick interval of nodular to tabular argillaceous limestone, equivalent to lower Rust, is abruptly overlain by dark shales with interbedded tabular micrites of the facies referred to as the Dolgeville Formation. Approximately one meter above this transition, dark shales have yielded graptolites diagnostic of the basal *Orthograptus ruedemanni* zone (C. Mitchell, personal commun.). It is probable that the Prospect Beds of the Rust are approximately equivalent to these dark shales to the southeast. If so, then indirectly at



very dark shales ("Valley Brook Shale") in the more basinal Flat Creek ("Canajoharie") Formation to the southeast. This abrupt deepening may record either a pulse of subsidence in the foreland basin related to tectonic loading in the Taconic Orogen, or a minor eustatic sea-level rise, or both. Whatever the case, there appears to be a widespread interruption in the general deposition of nodular limestones which characterize most of the Rust Formation. That tectonic action was involved is suggested by the fact that the quarry beds are overlain abruptly by thicker bedded limestones and channelized nodular limestones, which have undergone severe synsedimentary deformation (upper disturbed zone of Kay, 1943).

The Walcott-Rust quarry beds grade upward into thin nodular limestones ultimately capped by shelly packstones that were deposited prior to the development of deformation zones. The uppermost Rust and overlying Steuben limestones record a general upward shallowing trend from deeper shelf to very shallow current agitated crinoidal shoals. This regression may represent tectonic uplifting of an arch or forebulge associated with down-to-the-east basin subsidence. However, following a period of general shallowing the region of Trenton Falls experienced an abrupt pulse of deepening during which black shales spread over the entire area.

In terms of sequence stratigraphy the Walcott-Rust Quarry beds represent an early highstand following a marine flooding surface. These are probably a part of a fourth or fifth order cycle or parasequence representing a few hundred thousand years of deepening and shallowing within the basin. However, the overall pattern may have been produced tectonically.

During the time of relative shelf deepening represented by the Walcott-Rust Quarry beds, the typical accumulation of background bioturbated carbonate skeletal debris and mud was interrupted. In a regime of relative sediment starvation the primary sediments to accumulate were thin clay beds, and episodic carbonate silts and muds were deposited from storm-generated gradient or turbidity currents. The latter apparently moved from northwestern shelf areas to the southeast down a somewhat steepened ramp that led into the dysoxic foreland basin. The well preserved and diverse trilobites and echinoderms represented in the Walcott-Rust quarry beds reflect a deeper shelf community that developed during times of rather low net sedimentation and minimal bioturbation of the bottom. These communities were episodically smothered by sediment layers resuspended by storms in shallower water. To the east these deeper shelf conditions gave way to dysoxic organic rich mud bottom of the Flat Creek Formation which also shows episodic disturbance by mud layers (i.e., thin bioturbated layers separating barren or sparsely fossiliferous mudstones; layers of well preserved graptolites and *Triarthrus* trilobites).

Somewhat similar facies occur at the bases of several other cycles and some have yielded complete trilobites and crinoids although not in such profusion as that found in the Walcott-Rust Quarry beds. Deeper shelf conditions throughout the Trenton seem mainly to have been characterized by trilobites such as *Isotelus* and *Flexicalymene*. *Ceraurus* is typically rarer. The Walcott-Rust Quarry beds show a unique epibole of *Ceraurus* (see Brett and Baird, 1997, for general discussion). Conversely, *Flexicalymene* is not particularly common in these sediments. It remains uncertain what environmental conditions favored one species over the other.

#### DETAILED TAPHONOMY AND SEDIMENTOLOGY

Trilobite material is common throughout the quarried interval but the best preserved and most abundant articulated trilobites are found in four layers (Fig. 3).

*Layer 3.*—The lowest of the rich trilobite layers is layer 3.

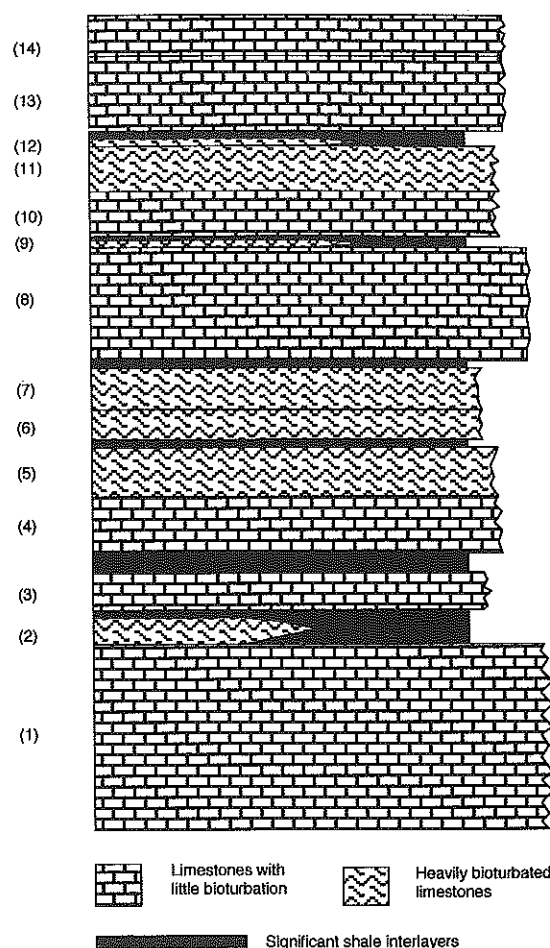


FIGURE 3—Primary trilobite layers in the Walcott-Rust Quarry (Layers 3, 4, 8, 13, and 14). The layer numbering, on the left side, corresponds to the layer references in the paper. Layer 1 forms a small waterfall approximately 45 meters south-southwest of a culvert under the abandoned railroad grade. Layer 1 also forms the northeast dipping base of the quarry. This same layer is exposed on the east side of West Canada Creek immediately south of the bridge at Prospect, New York. At this exposure the layer dips to the south and is underwater where it crosses the creek. Layers 1 through 14 are 0.88 meters thick at the quarry site.

This layer varies from 10 to 50 mm in thickness and has a complex history, as it includes at least two beds. The lower portion is a homogeneous calcilutite or micrite with scattered vertical burrows. The upper part is laminated dark and light calcisiltite and siltstone grading into mudstone. The lower trilobite bed also displays dark calcisiltite bands suggesting interruptions in the deposition of the layer.

The base of the lower bed (i.e., the base of layer 3) contains numerous articulated trilobites. Layer 3 was called the *Ceraurus* layer by Walcott (1875c) because of the very common occurrence of whole *Ceraurus pleurexanthemus* on the base of the layer, within it and on the upper surface. Although *Ceraurus* is the most common trilobite, *Meadowtownella*, *Flexicalymene*, *Achatella*, and *Calyptaulax* are also found on the base of the layer in the same order of abundance as listed. A similar population of trilobites is also found in the immediately subjacent tightly adhering shales. Trilobites are typically found with part of the exoskeleton within the shale and part within the lowest portion of the limestone. Those trilobites on the base are almost always dorsal surface down, i.e., upside-down (>98 percent)

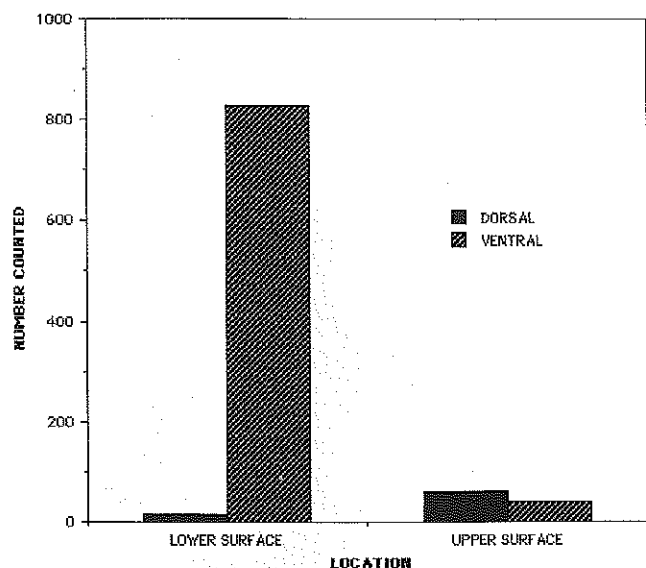


FIGURE 4—The attitude or orientation of the *Ceraurus* on the base and upper surface of layer 3, the “*Ceraurus* layer.” The *Ceraurus* on the base are more than 98 percent ventral surface uppermost and those on the top of the layer are 60 percent dorsal surface uppermost.

(Fig. 4). There is a broad distribution of sizes from 3 to 38 mm in length with the mean being at ~8 mm (Fig. 5). There is also some current alignment from the ENE to the WSW (Fig. 6). In addition, the crinoids *Cincinnaticrinus multibrachiatus* and *Ectenocrinus simplex* are common on this surface, some with long pieces of stem articulated but never with holdfasts. *Prasopora lenticularis* is also found on the base in abundance. This latter, uncommon bryozoan has not been reported since late in the last century (Roger Cuffy, personal commun.). Many specimens of this bryozoan display a unique wedge-shaped attachment scar attributed to a hyolith that served as a substrate for initial settlement (Brett and White, in preparation).

*Ceraurus*, particularly, and *Flexicalymene* are also found within layer 3. It was in these trilobites that Walcott first discovered unequivocal trilobite appendages (Walcott, 1876). The internal trilobites within the layer are mostly found prone, dorsal surface down, but occasionally they are semi-enrolled. Appendage preservation is exclusively within the semi-enrolled specimens.

The upper bed of layer 3 shows cross-laminated silts and laminated scour fillings. The laminae dip primarily to the northwest. *Ceraurus* are also found on the upper surface of the layer but in much lower concentrations than on the base. This surface features larger trilobites (Fig. 5) than that on the base and 60 percent of the specimens are dorsal-surface-up (Fig. 4). In addition to the trilobites, articulated crowns of *Iocrinus trentonensis* Walcott, 1883, are commonly found on this upper surface. These crinoids are rare elsewhere in the quarry. The crinoids commonly have short pieces of the stem attached and some are partially buried in the first few millimeters of the uppermost limestone. Many of the crinoids exposed on the upper surface show some disarticulation, but the parts are rarely scattered. One explanation for this preservation is that the crinoids were killed during the later stages of the event and lay exposed on the surface for a short time. Just as decay induced disarticulation began, another layer of siliciclastic silt was deposited on top of them.

**Layer 4.**—Layer 4 is separated from layer 3 by a calcareous shale bed. This layer is an amalgamated, irregular interval; 70 to 80 mm thick, composed of two closely stacked beds, a lower

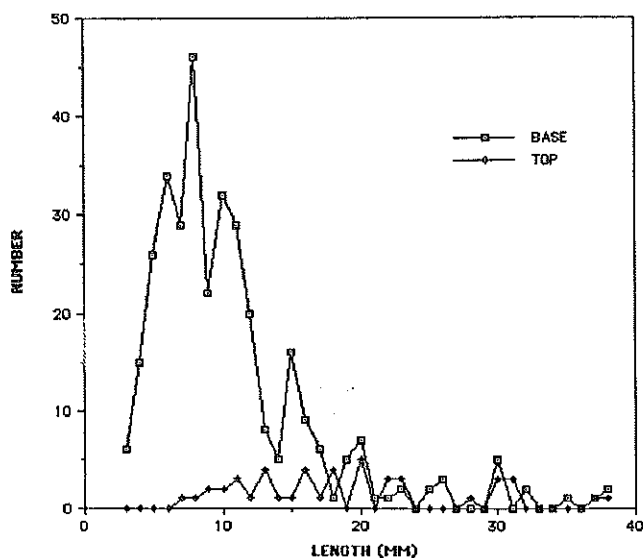


FIGURE 5—The length (sag.) of the *Ceraurus* found on the base (squares) and the top (diamonds) of layer 3.

calclutite and an upper calcisiltite to fine calcarenite. These divisions are more closely demarcated than are the beds in layer 3.

The lower bed is lightly burrowed and the upper bed moderately bioturbated. The sole of the basal calclutite is sparsely fossiliferous with trilobites, echinoderms, brachiopods and unidentified debris. Rare articulated specimens of the trilobite

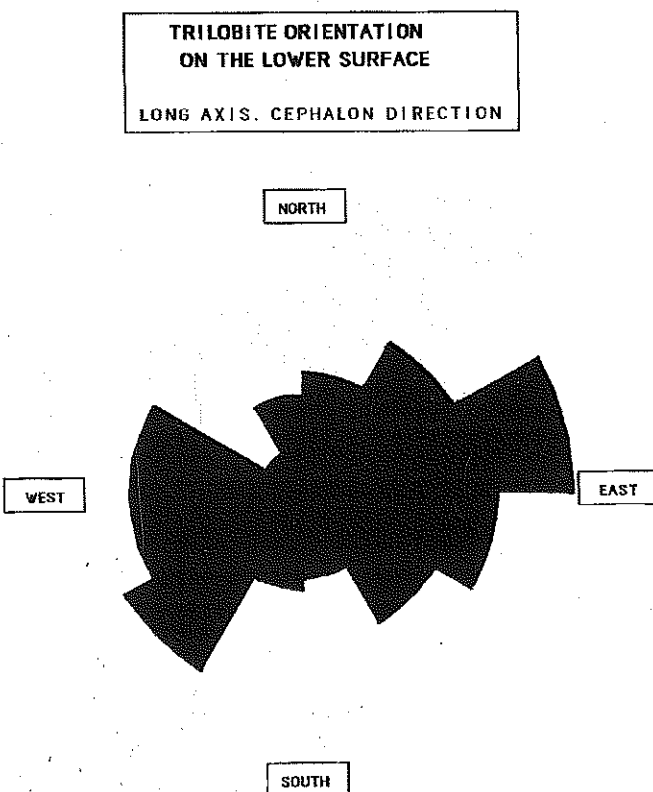


FIGURE 6—The azimuthal orientation of the *Ceraurus* on the base of layer 3. The orientation is measured along the long axis towards cephalon. For plotting purposes the data were grouped in 30 degree increments.



*Sphaerocorphe robusta*, the stylophoran *Ateleocystites balanoides* and an unidentified crinoid are found on the base. The top of this lower bed exhibits a sharp contact with the upper bed; it also shows apparent scour fills of laminated light and dark calcisiltite or very fine calcarenite.

Layer 4 is called the *Isotelus* layer because of the number of small, whole *Isotelus* taken from the interior of the unit. Two species are represented, *Isotelus gigas* and *Isotelus walcotti*. They are all small holaspids oriented somewhat randomly within the layer. Of the *Isotelus* collected from this layer, 31 had the dorsal surface uppermost; 16 had the ventral surface uppermost; 10 are of uncertain orientation; and four are nearly vertical in the matrix, two with cephalon up and two down. The specimens are prone (not enrolled), fully inflated, and undistorted, arguing for an early cementation of the bed before significant compaction.

The upper bed of the layer is highly undulatory as a result of soft sediment deformation. It is tightly welded to the overlying layer 5 and only separates after significant weathering. Fossils are not apparent on this surface.

Because of the presence of *Isotelus walcotti* and *Sphaerocorphe robusta*, which are not known anywhere else in the Rust Formation or in the entire New York Trenton Group, this layer can be considered an epibole (see Brett and Baird, 1997 for a discussion of epiboles) marked by the abundance of normally rare and unusual species not recorded elsewhere in the area. Whether these trilobites record a short term in migration from another area is unknown.

Layer 8.—Layer 8 is the next higher bed that contains articulated trilobites. This unit consists primarily of a tabular calcilutite or micrite and is commonly amalgamated to a lower hash bed. Accordingly it is generally impossible to observe details of the base of the calcilutite. The layer is about 10 cm thick, on average, and highly burrowed with some burrows extending to the base. Well preserved fossils are found scattered throughout the interior matrix but, as a rule, not on the base or top.

*Ceraurus* is the most common trilobite and is usually found in groups, although isolated individuals are not uncommon. Large *Isotelus gigas*, *Calyptaulax*, *Flexicalymene*, and *Hypodictyon* have also been found inside this layer. Orientation of trilobites within the layer is not recorded but appears to be random. In addition the uncommon fossil cnidarian(?) *Conchopeltis alternata* Walcott, 1877, (see Oliver, 1982) has been found near the base of the micritic portion.

Layer 13 (14).—Layer 13 (14) is distinguished from those previously mentioned in that it is fine grained, fossiliferous calcarenite or biomicrite. This layer is highly lenticular, 40 to 80 mm thick and associated with a package of layers of similar composition and character. Due to the lenticular nature of this and the immediately adjacent layers it is often difficult to distinguish them in different parts of the quarry. The compositions are also near identical. In the thicker portions, the base is fossiliferous with occasional specimens of *Ceraurus*, *Meadowtownella* and the machaeridian *Lepidocoleus jamesi*. The interior of the layer has trepostome bryozoans and orthoconic nautiloids. The nautiloids are spar-filled, indicating that living individuals were buried in the event which formed the bed. Inside this layer large *Isotelus gigas*, *Flexicalymene*, *Hypodictyon*, *Bumastoides holei*, and *Amphilechus cornutus* have been found.

#### TAPHONOMY: SUMMARY AND INTERPRETATIONS

Of the more than 50 beds (35 layers), 22 were found to yield at least one complete articulated trilobite and/or echinoderm (Fig. 3, Table 1). Hence, nearly half of these units show some evidence of being deposited rapidly as short-term events. Complete trilobites are most typical of the calcilutites, but are also

found in the shales and a few fine calcarenites. Those in shales may be underrepresented due to weathering by acidic surface waters or because these more time rich deposits did not furnish the conditions for preservation of whole fossils. Exuviae and parts of the four most common trilobites *Ceraurus*, *Flexicalymene*, *Isotelus gigas*, and *Meadowtownella* are abundant throughout the layers.

The limestones of the quarried interval, for the most part, are lightly burrowed but not bioturbated micrites. They display sharp bases, with some evidence of scour, and some show thin based layers of fine calcarenites that fine upwards into micrites. The tops are irregular, burrowed, and may contain thin skeletal hash beds. In addition to the burrowing within the micritic layers there are occasional lingulid brachiopods in life position. The limestones beds are separated by brownish-gray, calcareous claystones (shales). The shales are rich in echinoderm debris, trilobite exuviae, small brachiopods and other evidence of a normal marine bottom fauna.

The trilobite-bearing layers are the result of rapidly deposited limey muds. This sedimentologic evidence indicates that most of the fine-grained carbonate layers of the Walcott-Rust Quarry beds were derived from storm deposits from the north and west, closely enough spaced, through months or years but not tens of years, to prevent or inhibit bioturbation but allow normal benthic fauna to inhabit the newly deposited substrate. Currents deposited siliciclastic material from the east, resulting in a gradual buildup of the shaly interlayers.

That most of the trilobites are found on the lower surfaces of the various layers is worth commenting upon. A collecting bias is commonly introduced by the practice of examining bed surfaces but not careful, and labor intensive, breaking down of the rock and looking for internal fossils. However, in this study this effort was made and yet most of the trilobites were still found to be on the basal surface. (Very small trilobites, however, are difficult to recognize in freshly fractured rock.) Benthic fauna that are killed and buried by an event flow might be expected to be at or near the base of the layer. Any significant transport of the bottom fauna by the event sediments would have resulted in trilobites mixed within the layer or within the lower part of the event. High mortality within the event may be because of the sediment itself, or changes in water temperature or geochemistry. Churning of the bottom sediments may have released hydrogen sulfide, resulting in rapid immobilization and death of the benthic organisms (see Brett and Seilacher, 1991).

It has long been observed that most complete specimens are found upside-down. At the same time there is little in the way of actual statistics for most occurrences and these comments must then be considered anecdotal. Walcott (1875c) found over 95 percent of the *Ceraurus* on the lower surface of the "Ceraurus layer" upside-down. Our data from over 800 specimens put this figure at over 98 percent. Walcott also observed that other trilobites on the lower surface of bedding planes, with rare exception, were dorsal-surface-down. This is also our observation. One must then consider mechanisms which explain these and the far more general observation of commonly inverted trilobites. There are at least four explanations for this phenomenon.

1) The trilobites normally swam upside-down and were trapped while swimming up and away from the bottom trying to escape the burial event [the conjecture that trilobites swam upside-down was first made by Burmeister (1846). At the time he was unaware that trilobites had appendages enabling walking on the bottom.]. This is a comfortable rationalization and may be true for those trilobites that might well have been occasional swimmers. It is harder to envision large smooth carapaced trilobites such as *Isotelus* using this mode of escape. However the

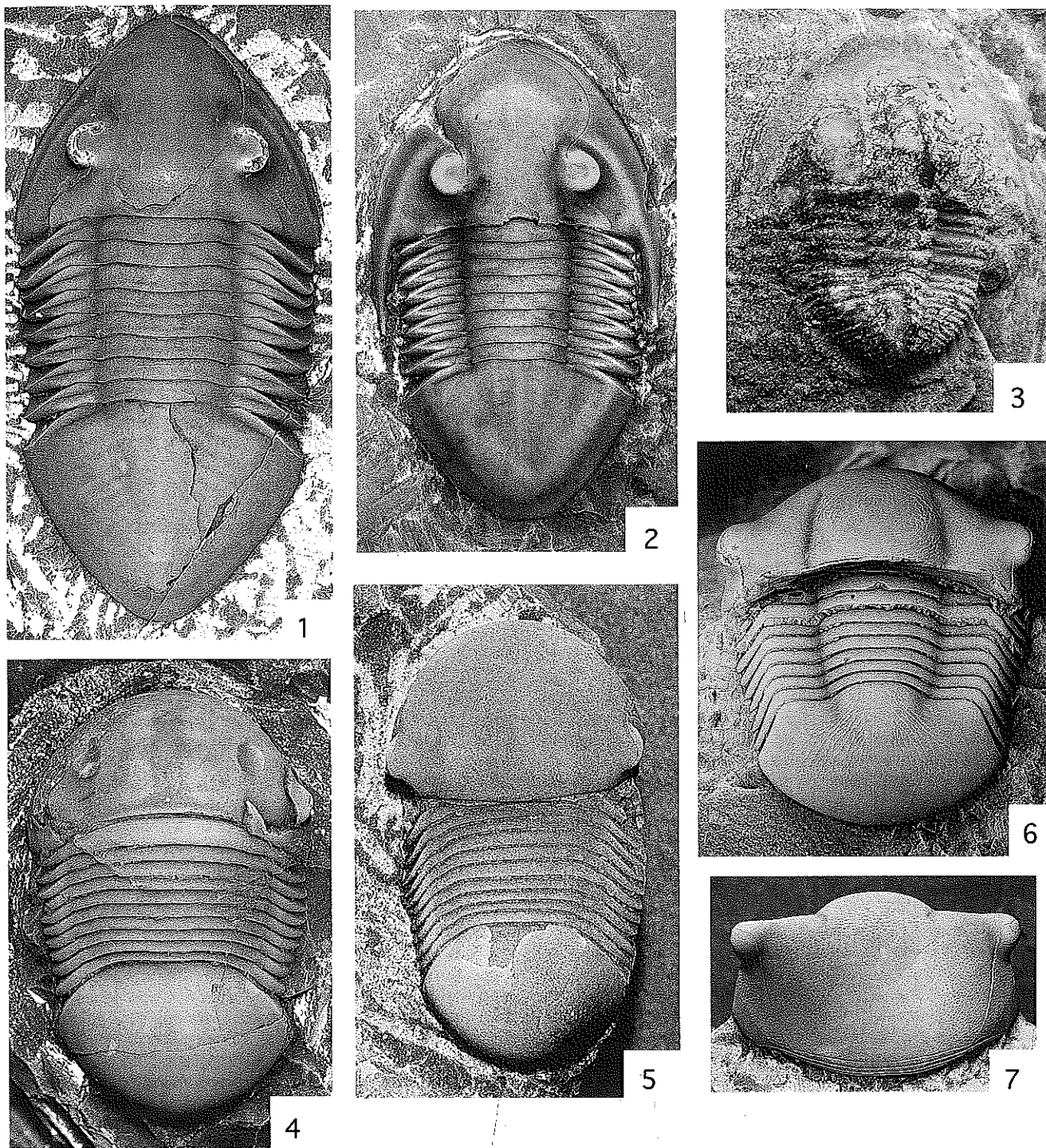


FIGURE 7—1, Neotype of *Isotelus gigas*, MCZ 100938, 52.2 mm long,  $\times 2$ , from inside layer 4. 2, Holotype of *Isotelus walcotti*, USNM 498807, 31.6 mm long,  $\times 2.5$ , from inside layer 4. 3, Partially exfoliated exoskeleton of an indeterminate asaphid meraspid, USNM 497034, 3.8 mm long,  $\times 16$ , the layer is unknown. 4, Partially exfoliated dorsal exoskeleton of *Bumastoides holei*, MCZ 101148, 37 mm long,  $\times 1.9$ , the specimen has been repaired on the lower left side of the cephalon, the lunettes are clearly visible on the interior mold, the layer is unknown. 5, Holotype of *Bumastoides porrectus*, MCZ 101147, 23.4 mm long,  $\times 3.2$ , the lunettes are seen as faint depressions adaxial to the anterior visual surface, the layer is unknown. 6, 7, *Nanillaenus americanus*, MCZ 112861; 6, the dorsal view of the exoskeleton, 21 mm long,  $\times 2.5$ , the layer is unknown; 7, view of the anterior cephalon,  $\times 2.5$ .



extant *Limulus* swims upside down and it is not shaped for easy swimming.

2) Trilobites that were killed and then lifted up into the water column or into the event mud flow would, if allowed to settle undisturbed, fall back to the bottom convex-surface-down or upside-down (Beecher, 1894), i.e., the "falling leaf effect." This mechanism requires that there be little in the way of disturbing current during the fall back. In the presence of a current, one might expect trilobites on the bottom to be flipped to their more stable orientation, convex surface up. Nonetheless, inverted specimens, at least in layer 3, are apparently current-aligned. It is not at all clear whether the type of currents involved in deep marine burials, or the shape of trilobites with their ventral appendages, are comparable to the more shallow wave induced currents which result in the convex-up orientations of bivalve shells.

3) Dead trilobites on an undisturbed surface might have generated decay gases within the body, if they were dorsal-surface-up. As the gases escaped around one edge, bubbles of gases escaping might then have flipped the trilobite over (Hicks in Walcott, 1918). This might have happened in a completely undisturbed state. However, studies have shown that articulated marine arthropods when left undisturbed disarticulate in days (Allison, 1986). Given the inevitable presence of scavengers, it is also highly unlikely that a whole articulated arthropod skeleton would survive the time necessary to be buried by gradually accumulating silt or carbonate mud.

4) Most trilobites enroll, and it is assumed this is a defense or stress-related mechanism. Even among those trilobites that were not strong enrollers most can bring the ventral surfaces of their cephalon and pygidium together. It is a rare species that is not sometimes found in an enrolled or partially enrolled position. If a trilobite were killed while enrolled and then unrolled as the muscles relax, it would most likely be on its back, upside-down (Beecher, 1894).

Of these four potential mechanisms the only one which is very unlikely is number 3. The attitude of swimming trilobites (1) is unresolved and will probably remain that way. However, the preferred alignment (Fig. 5) for the trilobites on the base also suggests that in this case the *Ceraurus* were dead or disabled and not enrolled when current aligned. Mechanisms 2 and 4 also cover most of the cases where the species is unlikely to have been a good swimmer or to have adopted swimming as an escape mode or those cases where the environment suddenly became toxic. No single mechanism is likely to cover all the articulated trilobites and in some cases two or more, or even another unanticipated mechanism may occur. Much more quantitative data on orientation combined with sedimentological information is needed to resolve the issue.

The *Ceraurus* on the top of layer 3 represent a population of larger-size trilobites than those on the base and they are also mainly (60 percent) dorsal surface uppermost. It is possible that these trilobites were not killed in the event forming the upper bed of layer three but were buried by the siliciclastic event covering this upper surface.

Although *Isotelus* is commonly found enrolled in other localities, none of the many small ones found both by Walcott and us in layer 4 was so enrolled. Because their orientation is somewhat random and there is no evidence of them trying to escape one might conclude they were killed during the event and transported some distance to their final burial. If they had enrolled when they were first stressed and then killed, their muscles would relax and they would open during the transport. If they were killed and buried rapidly in place, one would expect to find some still enrolled, as has been observed in *Isotelus* in other event bed burials.

Layer 8 demonstrates another obrution deposit with trilobites caught up within a thick bed. At least two large, enrolled *Isotelus* were found, suggesting a rather rapid burial. The *Ceraurus* found throughout the thickness of this layer also suggests some were caught up and transported somewhat during the burial process.

*Preservation of trilobites appendages*—Specimens of *Ceraurus*, *Flexicalymene*, and *Meadowtownella* all show soft tissue and appendages preservation in the *Ceraurus* layer. Walcott sectioned over 2,200 specimens and reported on his findings (Walcott 1877a, 1881, 1918, 1921). Due to artifacts of the sectioning process Walcott made some important errors in his reconstructions. Raymond (1920) re-evaluated Walcott's sections and came to different conclusions. Størmer (1939, 1951) serially sectioned some Walcott specimens and constructed a model of some appendage structure of *Ceraurus*.

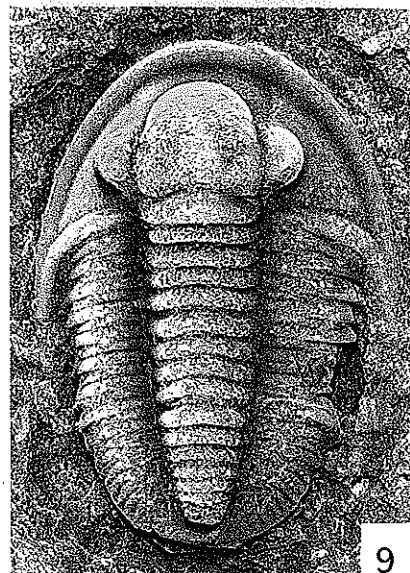
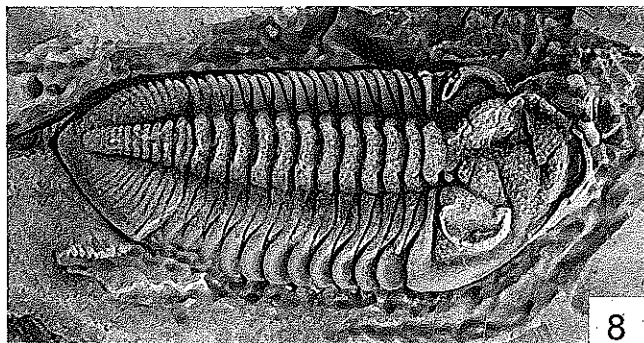
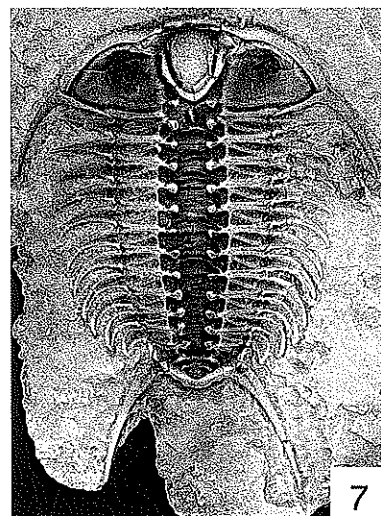
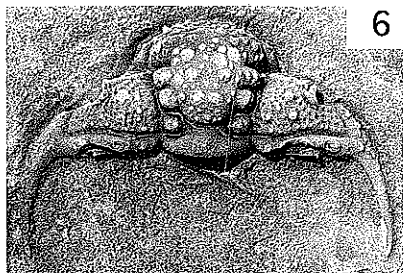
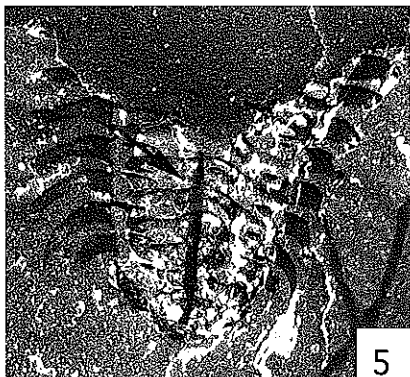
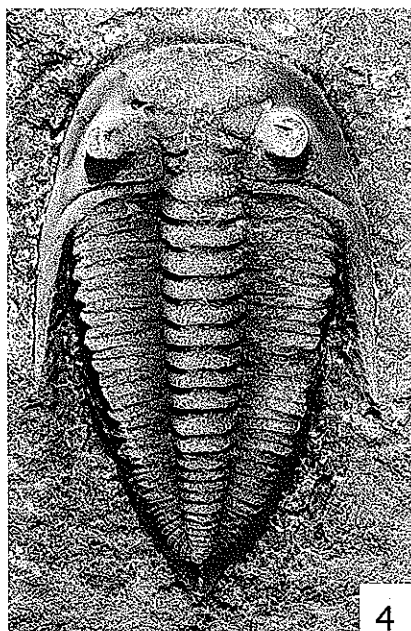
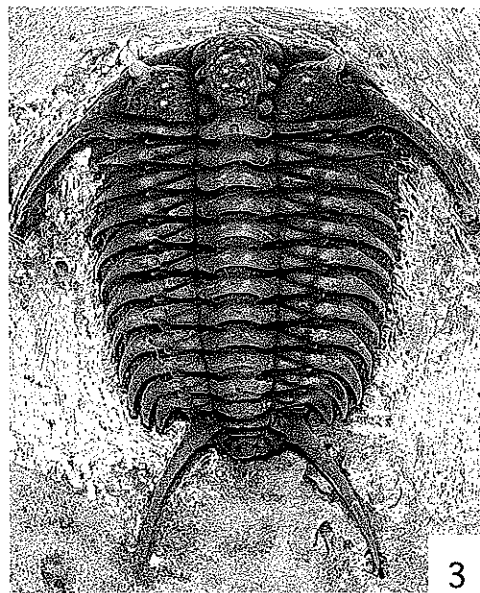
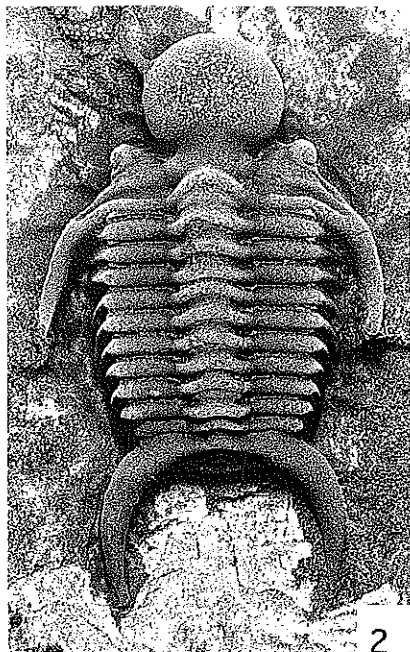
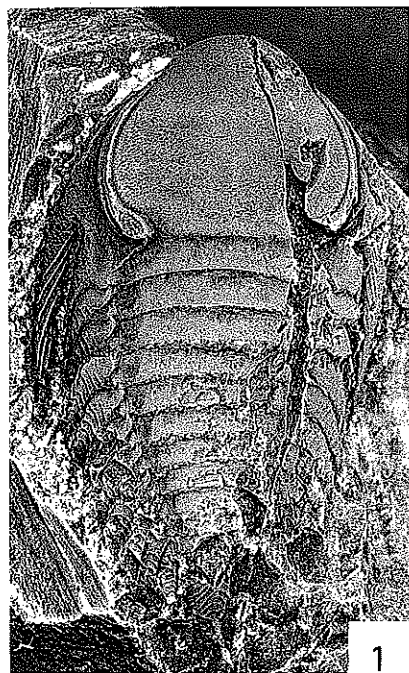
The appendages are uniquely preserved as sparry calcite inclusions in the limestone matrix (Fig. 9.9–9.11). Exceptionally fine detail of the appendages was preserved. These specimens differ from those with the preserved appendages available from other sites in that they have undergone very little compaction. The forces involved in the deposition of these sediments may have distorted the mobile appendages but they are in place and without the flattening seen in many other deposits. Figures 9.9 and 9.11 show the setae of the exopods of *Ceraurus* and *Flexicalymene* respectively. Figure 9.10 shows the endopod of *Ceraurus* with spines extending ventrally from the basis (see Ramsköld and Edgecombe, 1996, for the nomenclature). The presence of spines on the basis of some of these specimens has been discounted as a preservational phenomenon by Størmer (1951, p. 131). However, more information is needed, particularly as to the orientation of the trilobite, before this explanation can be accepted.

This type of preservation is only apparent when a specimen is sectioned and the cut surface is polished or a thin section made. Also only those specimens which are partially enrolled show a significant amount of this type of preservation. For these reasons it is unlikely that this preservation would be apparent to anyone collecting trilobites.

Microscopic examination of cross-sections reveals that the tergites show an early formation of plaque-like linings along with early calcite cement lining of the internal surfaces (Fig. 9.12). Some of this early calcite was partially replaced by pyrite.

A sequence of events was necessary for this appendage preservation to take place. The trilobites that show the best soft tissue preservation were buried when partially enrolled inside the layer. The burial was in lime sediment and that may have buffered the microenvironment against any acidic products of bacterial metabolism. The lime muds must have consolidated and cemented very rapidly to support the three-dimensional character of the preservation. A pelletal or flocculated sediment might explain this, because the high porosity of such sediments might facilitate cementation. The high concentration of organic matter made the closed microenvironment anaerobic; decay proceeded by sulfate reducing bacteria. Waste products of anaerobic sulfate reducing bacteria include bicarbonate and sulfide anions (Allison, 1990). In a slightly alkaline environment, saturated with carbonate, the bicarbonate build-up may have led to highly localized calcium carbonate precipitation. Pyrite formation, more common in such circumstances, may have been inhibited because of the small amount of iron in the carbonate sediment.

Even though this explanation rationalizes the observed phenomena, it does not explain why this type of preservation has not been observed elsewhere. It is difficult to observe this type of preservation unless one specifically looks for it, but Walcott claims to have sectioned hundreds of trilobites from different



layers and localities and did not find any other cases of preservation of appendages.

#### SYSTEMATIC PALEONTOLOGY

**Repository.**—Illustrated and referenced materials are housed in the Museum of Comparative Zoology, Harvard (specimen numbers prefixed MCZ), the New York State Museum (specimen numbers prefixed NYSM), the American Museum of Natural History (specimen numbers prefixed AMNH), the Geological Survey of Canada, Ottawa (specimen numbers prefixed GSC), and the National Museum of Natural History, Smithsonian (specimen numbers prefixed USNM).

Family ASAPHIDAE Burmeister, 1843  
Subfamily ISOTELINAE Angelin, 1854  
Genus ISOTELUS Dekay, 1824

**Type species.**—*Isotelus gigas* Dekay, 1824, from the Trenton Limestone, Trenton Falls, New York.

ISOTELUS GIGAS Dekay, 1824  
Figure 7.1

*Isotelus gigas* DEKAY 1824, p. 176, pl. 12, figs. 1, 2, pl. 13, fig. 1; DEMOTT, 1987, p. 71, pl. 3, figs. 1–11; RUDKIN AND TRIPP, 1989, p. 5–10, figs. 1.1–1.6, 2.1–2.3 (includes full synonymy).

**Material.**—The holotype of this species is lost (Rudkin and Tripp, 1989). The figured neotype (MCZ 100938, formerly MCZ 41) designated by DeMott (1987, p. 71) is from the Walcott-Rust Quarry. The neotype is 52.2 mm long.

**Occurrence.**—*Isotelus gigas* is a ubiquitous trilobite of the Trenton Group of New York. It is also reported from the equivalent rocks of Ontario, Canada (Ludvigsen, 1979a), the American mid-west (DeMott, 1987), and the Upper Ordovician rocks of Ohio (Babcock, 1996).

**Discussion.**—Many of the large articulated *Isotelus gigas* in older collections are from Trenton Falls and are from the upper Poland Member within the Trenton Gorge (Raymond, 1903). The specimens from the Walcott-Rust Quarry are in two populations. Numerous small holaspids, including the neotype, are from layer 4 and the larger specimens are from the overlying rocks. Small *I. gigas*, particularly those under 50 mm long, often have genal spines but these are lost as the trilobite became larger. The genal spines are narrow with a slight taper throughout their length. Canadian members of this species, in Trenton age rocks, retain their genal spines much later in their growth series.

ISOTELUS WALCOTTI Ulrich in Walcott, 1918  
Figure 7.2

*Isotelus iowensis* OWEN, 1852; RAYMOND, 1914, pl. 3, figs. 1, 2; WILSON, 1947, p. 24, pl. 3, fig. 4, pl. 4.

*Isotelus walcotti* ULRICH in WALCOTT, 1918, p. 133, pl. 24, fig. 1; RUDKIN AND TRIPP, 1989, p. 10, figs. 1.7–1.9. (includes full synonymy).

**Material.**—The holotype, USNM 498807, was first illustrated by Walcott (1918) and is 31.6 mm long. Additional specimens figured by Raymond (1914), Wilson (1947, pl. 4) and Rudkin

and Tripp (1989) are in the collections of the Museum of Comparative Zoology and the New York State Museum. All are from the Walcott-Rust Quarry. Wilson additionally mentioned and figured (pl. 3, fig. 4) a specimen from Canada.

**Occurrence.**—This trilobite is unreported from other areas of the Trenton or its equivalents in New York. Wilson (1947) reported asaphid tergites from the lower Trenton-upper Black River that have characteristics diagnostic of *I. walcotti*. DeMott (1987) assigned some asaphid pygidia, with uncertainty, to this species.

**Discussion.**—Small holaspids of this trilobite are found along with the small holaspids of *Isotelus gigas* within layer 4 of the Walcott-Rust Quarry. The two known, larger specimens are probably from the overlying rocks. This species is uncommon in the quarry. Walcott reported one out of fifty, 2 percent, of the small *Isotelus* found were *I. walcotti*. The genal spines of *I. walcotti* are retained throughout life and are significantly wider at the base than those of *I. gigas*. In small specimens (USNM 498807 and 61261, 31 and 65 mm long) the genal spines reach to the 7th thoracic segment while in a large specimen (MCZ 430, 127 mm long) the genal spines reach the 4th thoracic segment.

Indeterminate asaphid  
Figure 7.3

**Material.**—The figured specimen, labeled as *Gerasaphes ulrichiana* Clarke, 1894, is USNM 497034 from the Walcott-Rust Quarry.

**Discussion.**—Moore (1959, p. O355) considers *Gerasaphes* as an unrecognizable genus erected on small immature specimens. The illustrated specimen is an asaphid meraspis and because two different species of *Isotelus* are present in the quarry no definite assignment can be made.

Family ILLAENIDAE Hawle and Corda, 1847  
Genus BUMASTOIDES Whittington, 1954

**Type species.**—*Illaeus milleri* Billings, 1859, from Leray-Rockland Beds, near L'Original, Ontario, Canada.

BUMASTOIDES HOLEI (Foerste, 1920)  
Figure 7.4

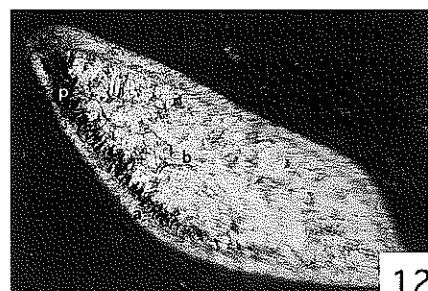
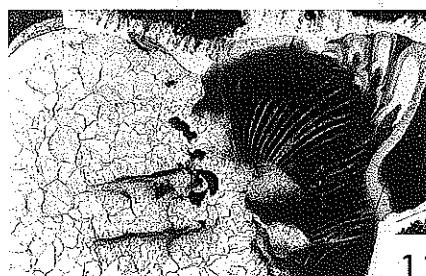
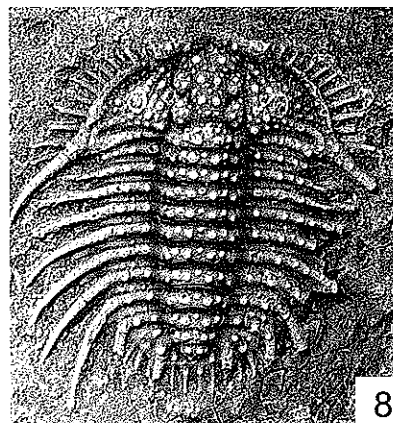
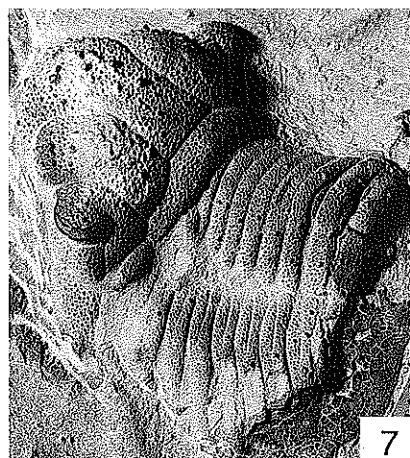
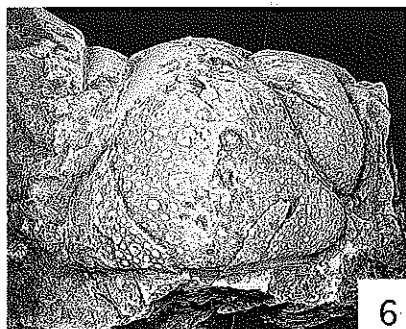
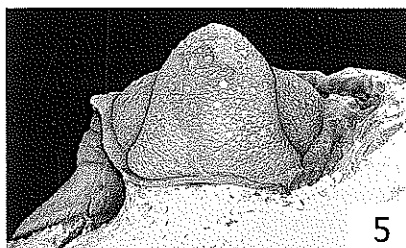
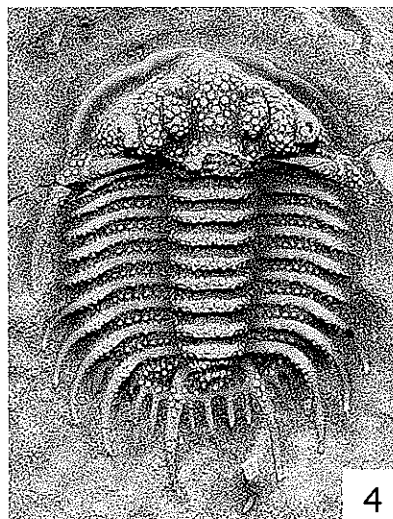
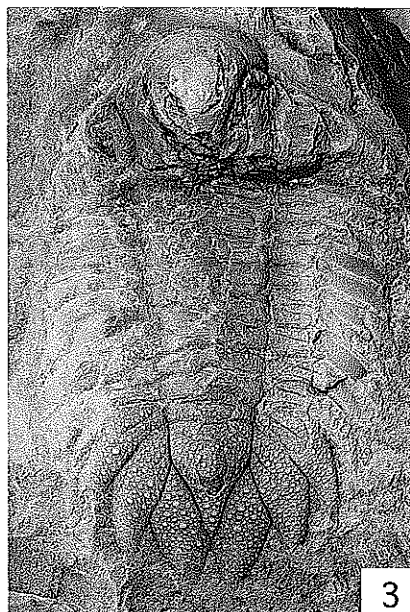
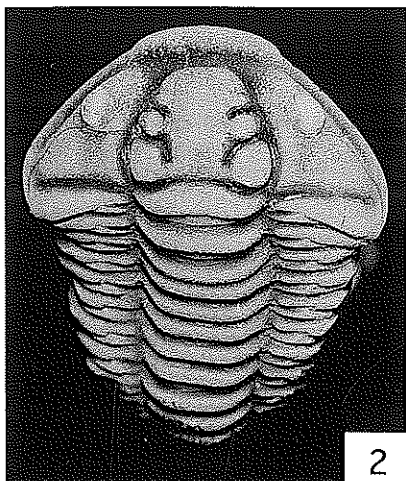
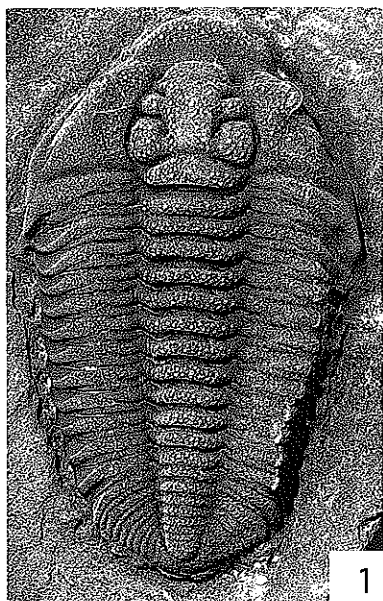
*Bumastus holei* FOERSTE, 1920, p. 214, pl. 21, fig. 15a, 15b, pl. 22, figs. 15a, 15b; RAYMOND, 1925, p. 116, pl. 8, figs. 5, 6.

**Material.**—The location of the type specimens is unknown. They are internal casts of a cranidium and an associated pygidium. They are from the Trenton age Kimmswick Limestone of Missouri. Specimens from the Walcott collection at the Museum of Comparative Zoology were identified as this species by Raymond (1925). The figured specimen is MCZ 101148 and is 37.0 mm long, the cephalon is 24.6 mm wide and the pygidium is 20.6 mm wide.

**Discussion.**—The original designation was on a cephalon and pygidium in close proximity and even then Foerste was not certain whether this was a new species or one already known. Foerste noted that the lunettes were relatively far apart and close

FIGURE 8—1, Lectotype of *Hypodicranotus striatulus*, MCZ 100986, 28 mm long,  $\times 2.8$ , the layer is unknown. 2, *Sphaerocoryphe robusta*, MCZ 110893, 13 mm. long (sag.),  $\times 4.5$ , from the base of layer 4. 3, 5, 7, *Ceraurus pleurexanthemus*; 3, MCZ 111708, 38 mm long (sag.),  $\times 1.5$ , from the upper surface of layer 3; 5, MCZ 111716, ventral view of the posterior exoskeleton showing a ferruginous trace of the gut (arrow), the length of the stain is 6.3 mm,  $\times 3.8$ , the anterior exoskeleton is still buried in the matrix, the specimen is one of a cluster of at least six *Ceraurus*, from the interior of layer 8; 7, MCZ 111715, ventral view of the exoskeleton, 33 mm long (sag.),  $\times 1.5$ , from the base of layer 3. 4, *Achatella achates*, MCZ 111713, length 22 mm, from the base of layer 3, ventral surface uppermost. 6, *Gabriceraurus* cf. *dentatus*, MCZ 111711, width across the genal spines 33 mm,  $\times 1.5$ , the specimen is from layer 21. 8, *Calyptaulax callicephalus*, MCZ 111712, 28 mm long,  $\times 2.6$ , the layer is unknown. 9, Unidentified proetid, MCZ 111714, 11.1 mm long,  $\times 6$ , from the base of layer 3.





to the posterior margin. The lunettes on the illustrations of Foerste are more posterior than those on the *B. holei* from the quarry. On the *B. holei* from the quarry a line between the anterior edges of the visual surfaces passes through or slightly behind the posterior edge of the lunettes. There are ten thoracic segments.

BUMASTOIDES PORRECTUS (Raymond, 1925)  
Figure 7.5

*Bumastus porrectus* RAYMOND, 1925, p. 114, pl. 8, figs. 7, 8; WILSON, 1947, p. 35, pl. 7, figs. 7–9.  
*Bumastoides porrectus* (Raymond). DEMOTT, 1987, p. 75, pl. 6, figs. 24–31 (contains full synonymy).

**Material.**—The illustrated holotype is MCZ 101147 from the Walcott-Rust Quarry. The holotype is 23.4 mm long, the cephalon is 13.4 mm wide and the pygidium is 10.9 mm wide.

**Occurrence.**—*B. porrectus* is a very rare trilobite in New York. DeMott (1987) also listed it from southwestern Wisconsin and northwestern Illinois. Wilson (1947) listed the trilobite from eastern Ontario and western Quebec.

**Discussion.**—There are 10 thoracic segments similar to *B. holei*. These two bumastoids are very similar and although Raymond noted that there is a greater disparity between the size of the cephalon and pygidium with the *B. holei* vs. *B. porrectus*, measurements on the specimens in the Museum of Comparative Zoology do not bear this out. A line between the anterior edges of the visual surfaces passes through the center of the lunettes which places the lunettes more posterior than those of *B. holei*. *Bumastoides milleri* (Billings, 1859) also occurs in the Middle Ordovician rocks of Ontario and the mid-west (DeMott, 1987). This species is reported to have 8–10 thoracic segments although most authors find 9 on specimens. There is a need for a systematic revision of this group.

Subfamily ILLAENINAE Hawle and Corda, 1847  
Genus NANILLAENUS Jaanussen, 1954

**Type species.**—*Illaenus conradi* Billings, 1859, from the Middle Ordovician of Quebec.

NANILLAENUS AMERICANUS (Billings, 1859)  
Figure 7.6, 7.7

*Illaenus americanus* BILLINGS, 1859, p. 371; BILLINGS, 1865, p. 329, figs. 316a–d, 318; Raymond and Narraway, 1908, pl. 60, figs. 1–3; WILSON, 1947, p. 31, pl. 7, figs. 3, 4.  
*Nanillaenus americanus* (Billings). LUDVIGSEN, 1979a, p. 37.

**Material.**—The type for this species is lost (Wilson, 1947, p. 31). Illustrated is MCZ 112861.

**Occurrence.**—*Nanillaenus americanus* is uncommon in the Trenton rocks of New York although more commonly reported in Ontario (Ludvigsen, 1979a).

TABLE 1.—Whole trilobites on or in the layers of the quarry, Cp, *Ceraurus pleurexanthemus*; Fe, *Flexicalymene* cf. *F. senaria*; Ig, *Isotelus gigas*; Iw, *Isotelus walcotti*; Pt, *Primaspis* cf. *P. trentonensis*; Dp, *Diacanthaspis parvula*; Sr, *Sphaerocoryphe robusta*; Ac, *Amphilichas cornutus*; Bsp, *Bumastoides* sp.; Na, *Nanillaenus americanus*; Hp, *Hypodicranotus striatulus*; Aa, *Achatella achates*; Cc, *Calyptraulax callicephalus*.

Layer	Trilobite												
	Cp	Fs	Ig	Iw	Pt	Dp	Sr	Ac	Bsp	Na	Hs	Aa	Cc
24	x												
23													
22	x												
21	x												
20	x												
19	x				x								
18	x				x								
17	x												
16													
15													
14	x		x		x			x	x		x		
13	x										x		
12													
11													
10	x	x	x										x
9	x												
8	c	x	x	—	—	—	—	—	—	x	x	x	x
7													
6													
5			x										
4	x	x	c	c	—	—	x	—	—	—	—	—	—
3	a	c	x	—	c	x	—	—	—	—	—	x	x

a = abundant; c = common; x = found; — = not found after thorough search.

**Discussion.**—Moderate numbers of whole specimens have been taken from the Walcott-Rust Quarry and are found in the National Museum of Natural History, the Museum of Comparative Zoology and the New York State Museum. *Nanillaenus americanus* is distinguished from the other illaenids present because it has significantly deeper axial furrows on both the cephalon and the pygidium. The lunettes are at the anterior end of the cephalic axial furrows. The layers where the specimens were found are unknown. Large cephalons are found in layer 4.

Family REMOPLEURIDIDAE Hawle and Corda, 1847  
Subfamily REMOPLEURIDINAE Hawle and Corda, 1847  
Genus HYPODICRANOTUS Whittington, 1952

**Type species.**—*Remopleurides striatulus* Walcott, 1875 from the lower third of the Rust Formation, Walcott-Rust Quarry, near Trenton Falls, N. Y.

HYPODICRANOTUS STRIATULUS (Walcott, 1875)  
Figure 8.1

*Remopleurides striatulus* WALCOTT, 1875b, p. 347, fig. 27A, a, b; RAYMOND, 1925, p. 57, pl. 3, figs. 4, 5.

FIGURE 9—1, 2, *Flexicalymene senaria*; 1, MCZ 111710, 28 mm long,  $\times 2.7$ , from the base of layer 3; 2, the neotype from the lower Trenton limestones near Middleville, New York, AMNH 29474, the cephalon is 17 mm wide,  $\times 2.8$ , the trilobite is partially enrolled and photographed such that the cephalon has the same orientation as Figure 9.1. 3, 5, *Amphilichas cornutus*; 3, holotype, NYSM 4533, 46 mm long,  $\times 1.5$ , the layer is unknown; 5, the anterior view of the cephalon of an articulated specimen, MCZ 112863, the anterior-most glabella is 11.5 mm wide,  $2\times$ , from layer 13. 4, *Meadowtownella trentonensis*, MCZ 111709, 10.6 mm long (sag.),  $\times 4.5$ , the layer is unknown. 6, 7, *Amphilichas conifrons*; 6, NYSM 9607, glabella, the holotype, the anterior glabella is 28.7 mm wide,  $\times 1.3$ , the layer is unknown; 7, MCZ 112864, cephalon and eight thoracic segments, the cephalon is 23 mm long,  $\times 1.3$ , the layer is unknown. 8, Paratype of *Diacanthaspis parvula*, MCZ 112862, the specimen is 8 mm long,  $\times 5.6$ , the layer is unknown. 9, 10, Thin sections of *Ceraurus pleurexanthemus*; 9, MCZ 104973,  $\times 3.7$ , section through the cephalic area showing calcite replacement of the exopods including the comblike setae or brachial processes, from inside layer 3; 10, MCZ 110933,  $\times 6.6$ , transverse section through the thorax showing the endopod with the basis (arrow) with spines, from inside layer 3. 11, Thin section of *Flexicalymene senaria*, MCZ 104959,  $\times 6$ , transverse section through a tightly coiled specimen showing the clublike ends of two exopods with their setae or brachial structures, from inside layer 3. 12, Cross-section of tergite of *Ceraurus pleurexanthemus*, two forms of calcite deposition, isopachous rim of early (bacterially produced) lining of the tergite (a), and sparry fill of later diagenetic calcite (b), also dark pyrite overgrowth of the isopachous calcite lining (p), from inside layer 3.



*Hypodicranotus striatulus* (Walcott). WHITTINGTON, 1952; LUDVIGSEN, 1979, p. 50, fig. 31A, 31B; LUDVIGSEN AND CHATTERTON, 1991, p. 620, pl. 1, figs. 1–28, text. figs. 1A, 2 (with complete synonymy); LESPÉRANCE AND DESBIENS, 1995, p. 7, figs. 3.1–3.5.

**Material.**—The lectotype, selected by Raymond (1925, pl. 3, fig. 4), is MCZ 100986. Hypostomes are found in fossil hashes and are not uncommon.

**Occurrence.**—Although only two complete dorsal exoskeletons of *H. striatulus* are described, the trilobite is widely distributed in the Trenton age rocks of New York, Ontario, Quebec, the American mid-west, and the Upper Ordovician of northwest Canada.

**Discussion.**—The lectotype specimen is damaged on the posterior third, and was figured incorrectly by both Walcott (1875b) and Raymond (1925). A short spine is present on the 8th thoracic segment and the pygidium is small and subrectangular (see Ludvigsen and Chatterton, 1991). Remopleurids are considered to be possible pelagic trilobites (Bergström, 1983; Fortey, 1985) which might explain the wide distribution of *H. striatulus*. The large, distinctive tuning fork-shaped hypostome is readily visible in fossil hash.

Family CHEIRURIDAE Salter, 1864  
Subfamily CHEIRURINAE Salter, 1864  
Genus CERAURUS Green 1832

**Type species.**—*Ceraurus pleurexanthemus* Green, 1832, from the lower Trenton Limestones near Newport, New York, USA.

CERAURUS PLEUREXANTHEMUS Green, 1832  
Figure 8.3, 8.5, 8.7

*Ceraurus pleurexanthemus* GREEN, 1832, p. 84, 5, fig. 10; RAYMOND AND BARTON, 1913, p. 528, pl. 1, fig. 1, pl. 2, figs. 1, 2, 7; EVITT, 1953, p. 33, pl. 7, figs. 1, 2, pl. 8, figs. 5–7.  
non *Ceraurus pleurexanthemus* Green. WHITTINGTON, 1941, p. 498, pl. 73, figs. 1–40.

**Material.**—The holotype is NYSM 4203. The holotype is from near Newport, New York. Rocks exposed near Newport are the upper Black River and lower Trenton Groups. The illustrated specimen, figure 8.3, MCZ 111708, is from the upper surface of layer 3.

**Occurrence.**—This trilobite is also reported from the Black River Group and from the Trenton equivalent rocks of Ontario and Quebec, Canada.

**Discussion.**—The specimens used by Raymond and Barton (1913) and by Evitt (1953) for their descriptions are from the Walcott collection at the Museum of Comparative Zoology and are all from the Walcott-Rust Quarry. *Ceraurus pleurexanthemus* is a common trilobite throughout the Trenton Group of New York but is rarely found articulated, or in good condition due to the weathering on exposed surfaces. It is most common in the deep shelf facies (Titus, 1986). In the quarry *C. pleurexanthemus* is found on many bedding planes in small numbers but it is abundant on the lower surface of layer 3 and to a lesser extent within, and on the upper surface, of the same layer. It is also commonly found within layer 8 and sometimes in groups of individuals. The specimens with appendages all occur internally in layer 3.

Genus GABRICERAURUS Přibyl and Vaněk in Přibyl et al., 1985

**Type species.**—*Ceraurus gabrielsi* Ludvigsen, 1979, from the Esbataottine Formation, District of Mackenzie, Northwest Territories.

GABRICERAURUS cf. DENTATUS (Raymond and Barton, 1913)  
Figure 8.6

*Ceraurus pleurexanthemus* Green. HALL, 1847, pl. 65, figs. 1d, 1h, 1l, 1m, pl. 66, fig. 1a–1g.

*Ceraurus dentatus* RAYMOND AND BARTON, 1913, p. 534, pl. 1, fig. 2, pl. 2, figs. 4, 5.

*Gabriceraurus dentatus* (Raymond and Barton). DEMOTT, 1987, p. 78, pl. 9, figs. 1–7, pl. 10, figs. 1–3; LESPÉRANCE AND DESBIENS, 1995, p. 15, fig. 5.1–5.3 (synonymy).

*Gabriceraurus hirsutius* Ludvigsen, 1979. HESSIN, 1989, p. 1204, pl. 1, figs. 1–7, Text figs. 2, 3a.

**Material.**—The holotype for this species at the Canadian Geological Survey is lost (see Hessin, 1989, p. 1207). The illustrated specimen is MCZ 111711.

**Occurrence.**—*Gabriceraurus dentatus* is reported from New York, Ontario, and the American mid-west. In New York it is most common in the lower Trenton Group but sparsely present throughout.

**Discussion.**—Because of the loss of the holotype and the lack of a good historical paratype Hessin (1989) renamed the species *Gabriceraurus hirsutius*. The International Committee on Zoological Nomenclature does not, however, accommodate changes in names when a properly illustrated and published description exists. *Gabriceraurus dentatus* is a widely known trilobite and a good photograph of the holotype exists (Raymond and Barton, 1913, pl. 2, fig. 5; see also Lespérance and Desbiens, 1995). *Gabriceraurus dentatus* differs from the more common *C. pleurexanthemus* in that in *G. dentatus* the eyes are opposite L2 while in *C. pleurexanthemus* they are opposite the anterior edge of L3. The specimen from the quarry differs from the more common lower Trenton specimens in that the eye is opposite the anterior margin of L2, further forward, and there are indications on nodes on the posterior cephalic border which are not seen on previously illustrated specimens (Hessin, 1989, pl. 1, figs. 1–7).

Subfamily DEIPHONINAE Raymond 1913  
Genus SPHAEROCORYPHE Angelin, 1854

**Type species.**—*Sphaerocoryphe punctata* Angelin, 1854, from the Upper Ordovician of Sweden.

SPHAEROCORYPHE ROBUSTA Walcott, 1875  
Figure 8.2

*Sphaerocoryphe robusta* WALCOTT, 1875a, p. 274, fig. 18a, 18b; WILSON, 1947, pl. 10, figs. 1, 2a, 2b.

**Material.**—The holotype is MCZ 110893. Illustrated is MCZ 110901. Articulated specimens are in the Museum of Comparative Zoology and the New York State Museum.

**Occurrence.**—The only other report of the species was by Wilson (1947) from the Sherman Fall beds at Hull, Quebec and was based on a glabella in a private collection.

**Discussion.**—This small cheirurid is found on one bedding surface, the base of layer 4, in the Walcott-Rust Quarry. Although small, the highly inflated, nearly spherical glabella makes this trilobite unmistakable. All the known specimens from the quarry are articulated and preserved with the ventral surface up.

Family PTEYGOMETOPIDAE Reed, 1905  
Subfamily PTERYGOMETOPINAE Reed, 1905  
Genus ACHATELLA Delo, 1935

**Type species.**—*Dalmanites achates* Billings, 1860, from Ottawa, Ontario, Canada.

ACHATELLA ACHATES (Billings, 1860)  
Figure 8.4

*Dalmanites achates* BILLINGS, 1860, p. 63, fig. 9; CLARKE, 1894, p. 726, fig. 44; FOERSTE, 1919, p. 397, figs. 8, 18a.

*Pterygometopus achates* (Billings). RAYMOND, 1921, p. 38, pl. 11, fig. 3. *Achatella achates* (Billings). DELO, 1940, p. 110, pl. 13, figs. 19–21; WILSON, 1947, p. 60, pl. 10, fig. 16; LUDVIGSEN, 1979a, p. 46, fig. 28A–B; LUDVIGSEN AND CHATTERTON, 1982, p. 2183, pl. 1, figs. 1–7 (includes full synonymy).

**Material.**—The holotype is GSC 1784. Specimens are found on the base of layer 3 within the quarry and in fossil hashes. Illustrated is MCZ 111713.

**Occurrence.**—Trenton age rocks of Ontario, Quebec, Illinois, Missouri, and New York (Ludvigsen and Chatterton, 1982).

**Discussion.**—Believing the holotype to be lost, Delo (1935) defined the genus from the specimen figured by Clarke (1894), NYSM 13360. The holotype is described and figured by Wilson (1947). *Achatella achates* is very distinctive as it has a posteriorly tapering body, long genal spines, tall, schizochroal eyes, and a triangular pygidium with an axial spine. *Achatella achates* is not a common trilobite in the Trenton Group; most specimens in New York have been found in the Rust Formation.

Genus CALYPTAULAX Cooper in Cooper and Schuchert, 1930

**Type species.**—*Calyptaulax glabella* Cooper, 1930 from the Whitehead Formation, Gaspé, Quebec.

#### CALYPTAULAX CALLICEPHALUS (Hall, 1847)

##### Figure 8.8

*Phacops callicephalus* HALL, 1847, p. 247, pl. 65, figs. 3a–i.

*Dalmanella callicephala* (HALL, 1859), p. 73.

non *Pterygomotopus callicephalus* (Hall). CLARKE, 1894, p. 731, figs. 51, 52.

*Calliops callicephalus* (Hall). DELO, 1940, p. 94, pl. 11, figs. 1–4; WILSON, 1947, p. 56, pl. 10, figs. 5, 6.

*Calyptaulax callicephalus* (Hall). SHAW, 1968, p. 86, pl. 12, fig. 2; LUDVIGSEN, 1979a, p. 40, fig. 24A.

**Material.**—The specimens figured by Hall (1847) are considered to be lost (Delo, 1940, p. 95). Delo used specimens from the Walcott-Rust Quarry in the Museum of Comparative Zoology from the Walcott collection, to define his genus *Calliops* and to describe *Calliops callicephalus*. Illustrated is MCZ 111712.

**Occurrence.**—*Calyptaulax callicephalus* is found throughout the Trenton in New York and has been reported in the upper Black River Group and Trenton equivalent rocks in Ontario. In New York it is most common in shallow shelf facies (Titus, 1986).

**Discussion.**—The cephalon of *Calyptaulax* is semicircular in outline and has a rounded genal angle. The eyes are schizochroal. The pygidium is subtriangular in outline with no axial spine. The pygidium differs from that of *Flexicalymene senaria* in that the axis of *C. callicephalus* is tapered for the anterior half and then parallel sided with nine or 10 axial rings. The pygidium in *F. senaria* tapers uniformly with six to eight axial rings. Because of the lack of the original type specimens and the small differences between *Calliops* and *Calyptaulax* Shaw (1968) considered *Calliops* to be a junior synonym of *Calyptaulax*. The various reported species of *Calyptaulax* (and *Calliops*) are very similar and the genus needs further study to differentiate the various species and morphotypes (Shaw, 1968).

Family CALYMENIDAE Burmeister, 1843

Subfamily CALYMENINAE Burmeister, 1843

Genus FLEXICALYMENE Shirley, 1936

**Type species.**—*Calymene caractaci* Salter, 1865, from rocks of the Caradoc Series, Acton Scott Lodge, Shropshire, England.

#### FLEXICALYMENE SENARIA (Conrad, 1841)

##### Figure 9.1, 9.2

*Calymene senaria* CONRAD, 1841, pp. 38, 49; EMMONS, 1842, p. 390, fig. 2; HALL, 1847, p. 238, pl. 64, figs. 3a–n.

*Flexicalymene senaria* (Conrad). WHITTINGTON, 1941, p. 493, pl. 72, figs. 1–27, 31–34, 38–40, 42–47, text fig. 1; WILSON, 1947, p. 48, pl. 10, figs. 11a, 11b, 12; EVITT AND WHITTINGTON, 1953, p. 49, pl. 9, figs. 1–16, pl. 10, fig. 1; STUMM AND KAUFMANN, 1958, p. 949,

pl. 123, figs. 1–11; ROSS, 1967, p. B14, pl. 4, figs. 1–6; LUDVIGSEN, 1979a, p. 46, fig. 29.

**Material.**—No type specimen was illustrated or designated by Conrad. Ross (1967) selected a specimen illustrated by Hall (1847, pl. 64, fig. 3a–c) as the neotype, AMNH 29474 (Fig. 9.2). The old museum label gives the location as Middleville, New York which would place it from the lower Trenton. Stumm and Kaufmann (1958) illustrate the same specimen and list its location as "near Watertown, New York." Figure 9.1, MCZ 111710, is from the base of layer 3 in the quarry.

**Occurrence.**—*Flexicalymene senaria* is perhaps the most common trilobite from the Trenton of New York not only because it is distributed throughout but also because the robust exoskeleton is readily preserved. It is also reported from Michigan (Stumm and Kaufmann, 1958), Virginia (Evitt and Whittington, 1953), Ontario and Quebec (Ludvigsen, 1979a).

**Discussion.**—The neotype is a small holaspid approximately 35 mm. long. It does not show the very pustulose character to the exoskeleton that characterize specimens illustrated by Evitt and Whittington (1953) and Ross (1967, pl. 4, figs. 11–13). Ross contends that the figured specimen, from the Walcott-Rust Quarry, is clearly a different species than the neotype. The *F. senaria* from the quarry are very pustulose and all have short genal spines. This issue needs to be clarified.

Family ODONTOPLEURIDAE Burmeister, 1843

Subfamily ACIDASPINAE Salter, 1864

Genus MEADOWTOWNELLA Přibyl and Vaněk, 1965

**Type species.**—*Primaspis whitei* Whittard, 1961, from the Shelve Inlier (Llandeilo) in Shropshire, England.

#### MEADOWTOWNELLA TRENTONENSIS (Hall, 1847)

##### Figure 9.4

*Acidaspis trentonensis* HALL, 1847, p. 240, pl. 64, fig. 4a–f.

*Leonaspis? trentonensis* (Hall). WHITTINGTON, 1941, p. 502, pl. 74, figs. 31–37.

*Primaspis trentonensis* (Hall). PRANTL AND PŘIBYL, 1949, p. 149; ROSS, 1979, p. D8, pl. 4, figs. 8–14.

**Material.**—The holotype, AMNH 853/2, is from the Bay of Quinte near Belleville, Ontario. Numerous specimens are available from the quarry. Illustrated is MCZ 111709.

**Discussion.**—The genus *Meadowtownella* was erected by Přibyl and Vanek in 1965. Since then most of the former *Primaspis* have been assigned to this genus (Ramsköld, 1984, p. 241; Ramsköld and Chatterton, 1991, p. 342). *Meadowtownella* was also assigned to the subfamily Acidaspinae (Ramsköld and Chatterton, 1991). The holotype of *Meadowtownella trentonensis* is somewhat damaged and Ross (1979) feels there are significant differences between it and other, much better preserved *Meadowtownella* from the quarry. On the glabella L1 is significantly larger than L2. On the thorax there is a distinct row of 4 or 5 pustules in the interpleural furrow. *Meadowtownella trentonensis* is one of the most common trilobites from the quarry where it is very often found associated with both fenestrate bryozoans and *Prasopora*.

Subfamily ODONTOPLEURINAE Burmeister, 1843

Genus DIACANTHASPIS Whittington, 1941

**Type species.**—*Diacanthaspis cooperi* Whittington, 1941, from the lower Martinsburg Formation of Virginia.

#### DIACANTHASPIS PARVULA (Walcott, 1877)

##### Figure 9.8

*Acidaspis parvula* WALCOTT, 1877b, p. 16; WALCOTT, 1879, p. 69.

*Odontopleura parvula* (Walcott). CLARKE, 1892, p. 69; CLARKE, 1894, p. 744, fig. 61; WILSON, 1947, p. 43, pl. 10, fig. 8.

*Diacanthaspis? parvula* (Walcott). WHITTINGTON, 1941, p. 502.

**Material.**—The holotype is MCZ 110952, the illustrated specimen is the paratype MCZ 112862.

**Occurrence.**—*Diacanthaspis parvula* has not been reported anywhere else in New York. It is reported from Quebec (Wilson, 1947).

**Discussion.**—*Diacanthaspis parvula* is much less common than *Meadowtownella trentonensis*. On the glabella L1 and L2 are about the same size. They are proportionally smaller than the L1 on *M. trentonensis*. The thoracic pleural spines of *D. parvula* are proportionally longer and less curved than those on *M. trentonensis*. Pustules in the interpleural furrows are much reduced or absent on *D. parvula* and the axial and pleural nodes are strongly pustulose. The species has not been properly described.

Family LICHIDAE Hawle and Corda, 1847  
Subfamily TETRALICHINAE Phleger, 1936  
Genus AMPHILICHAS Raymond, 1905

**Type species.**—*Platymetopus lineatus* Angelin, 1854, from the Upper Ordovician Boda Limestone of Sweden.

AMPHILICHAS CORNUTUS (Clarke, 1894)  
Figure 9.3, 9.5

*Conolichas cornutus* CLARKE, 1894, p. 749, figs. 72, 73.

**Material.**—The holotype, figure 6.3, of *Amphilichas cornutus* is NYSM 4533. It is an articulated specimen from the quarry. Figure 6.5, is an articulated specimen, MCZ 112863. Both specimens are from the quarry.

**Discussion.**—When Hall (1847, p. 235) first published on the Middle Ordovician *Amphilichas*, as *Platynotus trentonensis*, he figured specimens from three locations. Carlisle, Pennsylvania, Middleville, New York and Cincinnati, Ohio. The specimen from Ohio is from the Upper Ordovician and is clearly not the same species as the original specimens of Conrad (1842) from Pennsylvania. The holotype of *A. cornutus* is a complete specimen from the Walcott-Rust quarry which is, unfortunately, damaged due to poor preparation. Except for its high, conical shape the cephalon has few diagnostic characteristics due to the damage. The pygidium is not damaged. In Clarke's original figure (p. 749, fig. 73) he shows a spine on the conical shaped glabella. No such spine exists. He also shows that the glabella widens out at the posterior margin. The glabella narrows at the composite lateral lobe and has a uniform width in the latter third of its length.

AMPHILICHAS CONIFRONS Ruedemann, 1916  
Figure 9.6, 9.7

*Platynotus trentonensis*, HALL, 1847, p. 235, pl. 64, fig. 1c.

*Amphilichas conifrons* RUDEMANN, 1916, p. 90, pl. 30, figs. 5–8.

**Material.**—The illustrated holotype, NYSM 9607 and paratype, NYSM 9608, of *Amphilichas conifrons* are from the Walcott-Rust Quarry. Another illustrated specimen, MCZ 112864, is incomplete with a cephalon and eight thoracic segments.

**Discussion.**—Ruedemann chose to compare his species with *A. trentonensis* which, because of the poor definition of *A. trentonensis*, leaves doubt as to exactly which specimens he was using. On *A. conifrons* the glabella is smoothly arched from anterior to posterior and has no conical character. The cranidia are clearly different. The paratype pygidium is not diagnostic. No articulated specimen of *A. conifrons* is known and there is no way of differentiating the pygidia of the two lichids.

Family PROETIDAE Salter, 1864  
Indeterminate proetid  
Figure 8.9

**Material.**—The illustrated specimen, MCZ 111714, is from the base of layer 3. The exoskeleton is slightly corroded by ground water. Additional, unprepared, specimens are in the collections of the Museum of Comparative Zoology and the National Museum of Natural History. All from the Walcott-Rust Quarry.

**Discussion.**—Proetids are rare in the Ordovician rocks of New York. *Proetus (Proetus) clelandi* Raymond (1905b) reported as possibly from the Chazy Limestone (see Shaw, 1968) is Middle Ordovician but the figured, and only, specimen is not of sufficient quality for an assignment. Raymond (1905b) reports a small axial node on the occipital lobe of *P. clelandi* which is missing on the quarry specimen. *Proetus undulostriatulus* (Hall, 1847, AMNH 30101) is from the Middle Ordovician Snake Hill Shales. Specimens have also been assigned to *Cyphaspis*. Specimens from the Upper Ordovician of New York in the Peabody Museum at Yale University, American Museum of Natural History and the National Museum of Natural History have the names *Cornuproetus beecheri* (Ruedemann, 1926), from Beecher's Trilobite Bed, and *Proetidella parviusculus* Hall (1860) (see Babcock, 1996, p. 96), a proetid from Ohio.

#### CONCLUSIONS

1) The fossiliferous beds of the Middle Ordovician, Rust Limestone (Trenton Group) Walcott-Rust Quarry represent a series of storm deposits, including obrution events. Many of the layers display a complex history as revealed by the taphonomy of the fossils.

2) Some of the layers yield an unusually rich trilobite assemblage from both a quantitative and a qualitative perspective. At least 17 trilobite species are represented by well-preserved, whole specimens. Most of the fossils come from four layers although infrequent material is found throughout the rest of the 35 layers examined.

3) The quarried interval also contains trilobites that are rare or absent in the Trenton Group elsewhere in New York. These uncommon trilobites apparently are absent in beds below and above those quarried which suggests they were short term immigrants into the area, probably from the north and west.

4) The trilobites on bedding planes are predominately ventral surface uppermost (upside down). In the case of *Ceraurus* greater than 98 percent on the base of layer 3 were inverted. This generality is true of all the trilobites found on the base of layers. Where *Ceraurus* was found in significant numbers on the top of layer 3 most were found dorsal surface uppermost. It is suggested they were escaping from the burial event and subsequently killed. On the base of layer 3 an alignment of *Ceraurus* exoskeletons to the east-northeast/west-southwest was observed.

5) Unique preservation of appendages in some trilobite specimens was the result of early cementation from organically derived carbonate, followed by spar filling of the interior cavity within the appendages. The lack of significant amounts of early pyrite replacement is probably due to the low iron content of the sediment.

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