MARGINAL-MARINE LITHOFACIES, BIOFACIES, AND ICHNOFACIES, CHADAKOIN AND VENANGO FORMATIONS (UPPER DEVONIAN), UNION CITY DAM, ERIE COUNTY, PENNSYLVANIA

by
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Scott C. McKenzie, and Alan Ostrander

INTRODUCTION

The spillway to Union City Dam, along the South Branch of French Creek, near LeBoeuf, Waterford Township, Erie County, Pennsylvania, exposes a long section through the upper part of the highly fossiliferous Chadakoin Formation and lower part of the Venango Formation. Although much of the section is contained in the highwall of the spillway, extensive bedding-plane exposures are present in places. The spillway is one of the most productive body fossil and trace fossil localities in Erie County. It also is rich in sedimentary structures. The abundance and diversity of biotic remains, trace fossils, and sedimentary structures combine to make this locality an outstanding one for the study of processes leading to lithofacies, biofacies, and ichnofacies development in a Late Devonian marginal-marine, environment dominated by siliciclastic sedimentation. The purpose of this paper is to discuss the paleontology and sedimentology of the Union City Dam section, and to interpret the depositional environments represented in this section.

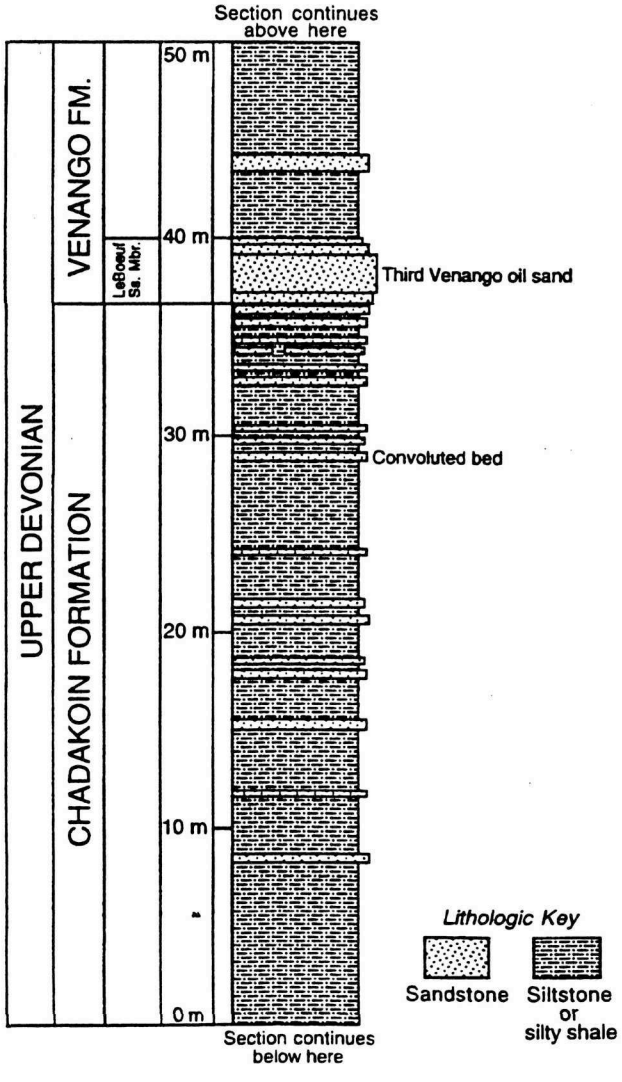

Figure 9- Columnar stratigraphic section of Upper Devonian strata exposed in the spillway of Union City Dam, Erie County, Pennsylvania.

STRATIGRAPHIC SETTING

Approximately 165 ft (50 m) of section are exposed in the spillway to Union City Dam (Figure 9). The section includes about 120 ft (37 m) of the upper part of the Chadakoin Formation and about 45 ft (13 m) of the lower part of the Venango Formation. The Chadakoin Formation is composed of medium gray and reddish-brown siltstones and shales with interbedded, lenticular, gray, white, tan, and reddish-brown sandstone layers. The Venango Formation is composed of white to tan quartz sandstones and conglomeratic

sandstones with interbedded medium gray to reddish-brown shale and silty shale layers. Here, as elsewhere, the contact between the two formations is transitional over approximately 55 ft (17 m). The Pennsylvania Geologic Survey has long considered the base of the first thick sandstone bed in this succession to be the base of the Venango Formation (e.g., White, 1881; Harper, 1998b). In Waterford Township, the lowermost sandstone interval of the Venango Formation is known formally as the LeBoeuf Sandstone Member of the Venango Formation. However, that interval is probably known better by the informal term "Third Venango oil sand." Chitaley and McGregor (1988) and Chitaley (1989) placed the Chadakoin Formation-Venango Formation boundary about 55 ft (16.5 m) below the base of the first thick sandstone interval in the Union City Dam section. For mapping purposes on a regional scale, we think it is more practical to use the base of the first thick sandstone bed as the contact between the two formations (Figure 9), just as the staff of the Pennsylvania Geologic Survey has done.

Siltstones, sandstones, and conglomeratic sandstones of the Chadakoin and Venango Formations seem to represent a wide range of paleoenvironments ranging from shallow marine through estuarine and tidal flats settings (Babcock and others, 1995). Previously, those units had been widely interpreted as having been deposited in a coastal to marine shelf setting (e.g., Caster, 1934, 1938; Willard, 1935; Bowen and others, 1974; Woodrow, 1985; Bridge and Droser, 1985) that was part of the Catskill delta complex of the Appalachian foreland basin (Faill, 1985). Streams emptied sediment westward into the foreland basin, and major shifts in sediment supply, accommodation space, and sea level (Dennison, 1985; Ettensohn, 1985) produced dramatic facies shifts in a roughly east-west direction (by present-day coordinates).

PALEONTOLOGY

A list of body fossils and trace fossils collected from the Union City Dam section is provided in Table 1. The fossils (Figure 10) include a mixed assemblage representing marine and nonmarine biofacies, as well as a diverse assemblage of trace fossils (Figure 11). Together, the body fossils (including their taphonomic

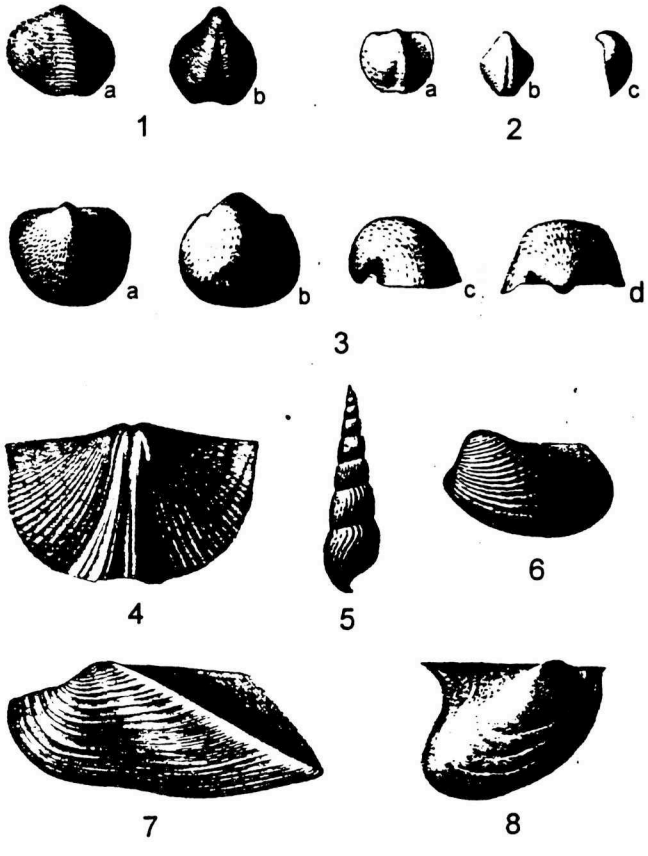

Figure 10- Sample body fossils collected from the upper Chadakoin Formation or lower Venango Formation in the spillway of Union City Dam. Illustrations, from Hall (1867, 1879, 1884, 1885). Brachiopods: 1. Athyrus angelica; 1a, brachial valve; 1b, pedicle valve. 2. *Ambocoelia gregaria*; 2a, bracial valve; 2b, pedicle valve; 2c, lateral view. 3. *Productella speciosa*; 3a, brachial valve; 3b, pedicle valve; 3c, lateral view; 3c, front view. 4. *Cyrtospirifer disjunctus*. Gastropod: 5. *Palaeozygopleura*. Bivalves: 6. *Grammysioidea communis*. 7. *Goniophora chemungensis*. 8. *Leptodesma potens*.

conditions) and trace fossils suggest a marine to marginal-marine depositional setting where there was input of parautochthonous organic matter from nearby marine and nonmarine sources.

Upper Chadakoin Formation-lower Venango Formation fossils from the Union City Dam are a mix of marine and nonmarine forms (Figure 10). Relatively abundant marine animals include the sponge *Armstrongia*, bryozoan fragments, inarticulate and articulate brachiopods, bivalves, orthocerid nautiloids, and separated crinoid ossicles or stem sections. Rare marine animals include some sponges, corals, hydrozoans, conulariids, gastropods, rostroconchs, ammonoid cephalopods, "worms," brittle stars, starfish, and placoderm fish plates. Acritarchs, presumably of marine origin, are part of the microfossil assemblage. Animals that may have been euryhaline or are of equivocal marine water/brackish water/fresh water habitat include lingulid brachiopods, horseshoe crabs, and some fish. Plants, all of nonmarine origin, that have been found in the Union City Dam section include various lycopods and a large assemblage of spores. Some organisms that would be expected of normal marine settings that are not known from the Union City Dam section include trilobites, phyllocarid crustaceans, conodonts, tentaculitids, and algal thalli.

Taphonomic conditions of the body fossils at Union City Dam indicate that most specimens have been transported from nearby sources. Evidence that any of the epibenthic organisms such as corals, bryozoans, brachiopods, crinoids, and conulariids were attached to the substratum and buried in place is lacking. Crinoids are broken into stem sections or fully separated into individual ossicles, indicating that final burial occurred at least several hours after the time of death. The rarity and low diversity of organisms such as acritarchs, corals, and most echinoderms, suggests that representatives of these groups lived in nearby subtidal areas and washed into their final burial places. Often, bedding plane views in the upper Chadakoin Formation show an alignment of elongate fossils similar to items left in strand lines on modern beaches and tidal flats. Bivalves, if found with both valves articulated, commonly have the valves splayed apart, or "butterflied." Occasional, lenticular, brachiopod-rich beds (coquinites) that are present in the upper Chadakoin Formation are likely lag deposits left in the wake of storms or other significant current activity, rather than in situ assemblages.

Trace fossils (Figure 11) tend to reinforce the interpretation of a shallow marine to marginal-marine depositional setting. A diverse trace fossil assemblage is present in the upper Chadakoin Formation-lower Venango Formation interval at Union City Dam. Traces present are indicative of the *Cruziana* ichnofacies. Some of the ichnogenera present are ones often encountered in marginal-marine areas where the animals that produced them are inferred to have been intermittently exposed to subaerial conditions, fluctuating salinity, or similar stressful conditions. Such traces include *Bifungites*, *Spirophyton*, *Skolithos*, and *Paramphibius*. *Protolimulus*, a resting trace produced by a horseshoe crab (described below), is also probably indicative of a very shallow subtidal to marginal-marine setting because of the inference that the trace maker was tolerant of marine, brackish, and fresh water.

One of the most striking trace fossils from the Union City Dam exposure is *Protolimulus eriensis*, which was described (as *Prestwichia eriensis*; Williams, 1885) from a specimen (Figure 11A and Figure 11B) collected near LeBoeuf, Pennsylvania. The original specimen was interpreted to be a cast of the ventral surface of a xiphosurid (horseshoe crab), and it replicated in detail some aspects of the ventral anatomy of that animal. Later, Packard (1886) erected the monotypic genus *Protolimulus* for Williams's specimen. Subsequent workers have mostly treated *Protolimulus eriensis* as a body fossil (e.g., Hall and Clarke, 1888; Lesley, 1889b; Caster, 1938), but Babcock and others (1995) demonstrated that it is a trace fossil using the original

specimen (Figure 11A and Figure 11B) and additional material (Figure 11C). Material for the reinterpretation was collected from the upper Chadakoin Formation and lower Venango Formation at the Union City Dam section. The trace represents concealment burrowing or perhaps resting behavior. It conforms in general shape to the inferred ventral anatomy of *Kasibelinurus randalli*, a horseshoe crab that is known from body fossils collected in association with *P. eriensis* in the upper Chadakoin Formation at the Union City Dam section (Babcock and others, 1995). Most specimens are hypichnial traces (protrusions from the bases of siltstone or sandstone beds; Figure 11A and Figure 11B), but a few known specimens are epichnial traces (indentations on the tops of siltstone or sandstone beds; Figure 11C). As hypichnial traces, *Protolimulus* resembles traces made by horseshoe crabs described as *Selenichnites* (see Romano and Whyte, 1990). As epichnial traces, *Protolimulus* resembles traces made by horseshoe crabs described as *Limulicubichnus* (see Miller, 1982).

Protolimulus eriensis is an interesting and important fossil for a number of reasons. First, because of its diagnostic shape, it can be readily equated with a trace maker. Most trace fossils cannot be unequivocally related to a unique trace maker. In the example of *Protolimulus*, the case for a horseshoe crab trace maker is strengthened by the co-occurrence of body fossils of *Kasibelinurus randalli*, an early horseshoe crab. Second, the trace fossils provide surprisingly detailed information about the ventral morphology of *Kasibelinurus*, and they provide detailed information about the burrowing behavior of that animal. Third, because the trace was produced in cohesive but unconsolidated sediment, it is possible to infer that horseshoe crabs actually burrowed in the places indicated by their traces. Body fossils can be transported, but traces produced in unconsolidated muds cannot be transported. Modern horseshoe crabs are rather euryhaline, and most known ancient species are likewise inferred to have had wide salinity tolerances. Horseshoe crabs often come ashore on beaches or tidal flats, particularly during breeding season. Together, these lines of evidence provide excellent support for a marginal-marine interpretation of parts of the upper Chadakoin Formation and lower Venango Formation in the area of LeBoeuf, Pennsylvania.

SEDIMENTOLOGY

Sedimentologic characteristics of the upper Chadakoin Formation-lower Venango Formation interval at Union City Dam provide strong evidence for marginal-marine conditions in places. The reddish-brown color of some of the rocks suggests the presence of reduced iron in the strata, but the color of sedimentary rocks is not always a reliable guide to original depositional environment because of diagenetic changes that may have occurred. Sedimentary structures present in the upper Chadakoin Formation include oscillation ripple marks, current ripple marks, flaser bedding, lenticular bedding, reactivation surfaces, mudcracks, and intraclastic conglomerate layers. The mudcracks indicate that at least some beds were subjected to cycles of wetting and subaerial desiccation. Flaser bedding, lenticular bedding, and reactivation surfaces are common on marginal-marine tidal flats. Oscillation ripple marks suggest shallow, relatively quiet water at times. Intraclastic conglomerates indicate that mud chips (probably caused by desiccation of mud) were eroded and deposited parautochthonously.

In the lower Venango Formation, lenticular sandstone layers suggest deposition as small barrier bars or as bar-finger sands. Occasional conglomeratic lenses within sandstone layers of the Venango Formation may be the result of nearby fluvial input into a coastal depositional environment.

Table 1. List of fossils from the upper part of the Chadakoin Formation and lower part of the Venango Formation, spillway to Union City Dam, French Creek, Erie County, Pennsylvania.

Organic-walled microfossils
- Undetermined acritarch

Kingdom Plantae
- Phylum Lycophyta
  - *Bisporangiostrobus harrisonii* (cone)
  - *Lycopodites mckenziei*
  - undetermined lycopod remains
- Spores
  - *Auroraspora solisorta*
  - *Convolutispora* cf. *C. oppressa*
  - *Corbulisporites cancellata*
  - *Cytospora cristifera*
  - *Dictyotriletes nefandus*?
  - *Emphanisporites* cf. *E. annulatus*
  - *E. rotatus*
  - *E.* cf. *E. pantagiatus*
  - *Hymenozonotriletes explanatus*
  - *H. granulatus*
  - *Knoxisporites dedaleus*
  - *Lophozonotriletes excisus*
  - *L. tuberosus*?
  - *Neoraistrickia* sp.
  - *Retusotriletes phillipsii*
  - *Rugospora flexuosa*
  - *Secarisporites* sp.
  - *Spelaeotriletes resolutus*?
  - *Vallartisporites pusillites*
  - *Verrucososporites nitidus*
  - *V. scurrus*

Kingdom Animalia
- Phylum Porifera
  - *Armstrongia oryx*
  - *Prismodictya*? sp.
  - undetermined hexactinellid
- Phylum Cnidaria
  - Class Anthozoa
    - *Pleurodictyum* cf. *P. americanum*
    - *Plumulina* sp.
  - Class Hydrozoa
    - *Plectodiscus* sp.
    - undetermined siphonophore
- Phylum? Conulariida
  - *Paraconularia wellsvillia*
- Phylum Bryozoa
  - *Sulcoretepora*? sp.
  - undetermined branching taxa
- Phylum Brachiopoda
  - Class Inarticulata
    - *Lingula arcta*?
    - *Trigonoglossa* sp.
    - *Petrocrania*? sp.
  - Class Articulata
    - *Ambocoelia gregaria*
    - *Athyrus angelica*
    - *Centrorhynchus* sp.
    - *Cyrtospirifer disjunctus*
    - *C. leboeufensis*
    - *Productella speciosa*
    - *Ptychomaletoechia* sp.
    - *"Pugnoides" duplicatus*
    - *Retichonetes* sp.
    - *Spinulicosta* sp.
    - *Syringothyrus* sp.
- Phylum Mollusca
  - Class Gastropoda
    - *Bellerophon* sp.
    - *Palaeozygopleura* sp.
    - *Platyceras* sp.
    - undetermined taxa
  - Class Rostroconchia
    - *Conocardium* sp.
  - Class Bivalvia
    - *Arctinodesma*? sp.
    - *Goniophora chemungensis*
    - *Grammysiodea communis*?
    - *Leptodesma potens*
    - *Limopteria*? sp.
    - *Modiomorpha quadrula*?
    - *Pholadella* sp.
    - *Ptychodesma* sp.
  - Class Cephalopoda
    - *"Gomphoceras"* sp.
    - undetermined orthoconic nautiloid
    - undetermined goniatite ammonoid
- Phylum Annelida
  - undetermined scolecodonts

Table 1 (cont.). List of fossils from the upper part of the Chadakoin Formation and lower part of the Venango Formation, spillway to Union City Dam, French Creek, Erie County, Pennsylvania.

Phylum unknown ("worms")
- *Sphenothallus* sp.
- undetermined worm

Phylum Arthropoda
- Class Chelicerata
  - *Kasibellinurus randalli*

Phylum Echinodermata
- Class Crinoidea
  - *Aorocrinus*? sp.
  - undetermined ossicles
- Class Stelleroidea
  - undetermined asteroid
  - undetermined ophiuroid

Phylum Chordata
- Placoderms
  - Arthrodires
    - *Dunkleosteous terrelli* teeth
    - undetermined placoderm armor
  - undetermined fish teeth and scales

Trace fossils
- *Clionolithes* ichnosp.
- *Conostichus* ichnosp.
- *Cruziana*? ichnosp.
- *Gordia* ichnosp.
- "ophiuroid burrow"
- *Palaeophycus* ichnosp.
- *Palaeosemaeostoma*? ichnosp.
- *Paramphibius* ichnosp.
- *Planolites* ichnosp.
- *Protolimulus eriensis*
- *Rhizocorallium* ichnosp.
- *Rusophycus*? ichnosp.
- *Skolithos* ichnosp.
- *Spirophyton* ichnosp.

Approximately 30 ft (9 m) below the base of the Third Venango oil sand (base of the Le-Boeuf Member of the Venango Formation) occurs a persistent sandstone bed showing soft-sediment deformation features ("Convoluted bed" in Figure 9). The origin of the soft sediment deformation is unknown; it may have been the result of relatively local rotation of coarse sediments the were quickly deposited over water-rich muds. Such a situation might occur in a small tidal channel on a tidal flat. Alternatively, the bedding may have been disrupted through seismically induced ground shake, in which case the bed would represent a so-called seismite.

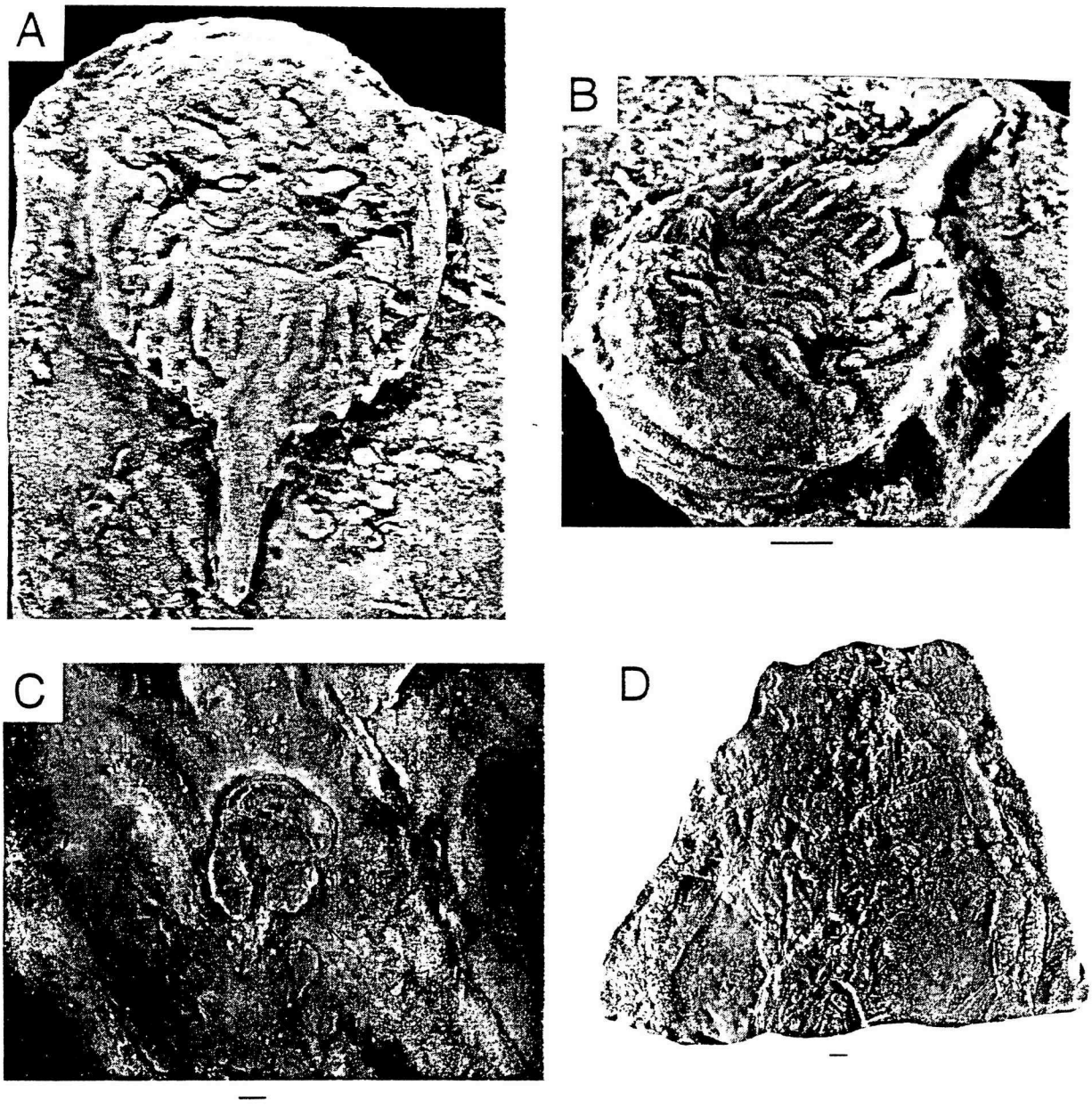

Figure 11 A & B- *Protolimulus eriensis*, holotype, U.S. National Museum of Natural History 62949, preserved as a hypichnial cast in sandstone, from the Upper Devonian "Chemung Group" (probably the LeBoeuf Sandstone Member of the Venango Formation), LeBoeuf, Erie County, Pennsylvania. Photographs are of bottom of sandstone slab (A) and oblique view of bottom of sandstone slab (B). Other small traces are present on the slab. Specimen loaned for study by Jann Thompson. C- *Protolimulus eriensis*, trace fossil representing burrowing behavior of a horseshoe crab, preserved as epichnial mold on surface showing oscillation ripple marks and flaser bedding. Other smaller traces, representing the activity of other organisms, are also present on the slab. Slab is from the upper Chadakoin Formation, spillway of Union City Dam. D- A variety of trace fossils, including *Cruziana*-like traces (probably constructed by horseshoe crabs), mostly preserved as casts on the undersurface of a sandstone bed. Slab is from the upper Chadakoin Formation, spillway to Union City Dam. Scale is 1 cm for all photographs.

0.3 86.6 Park the buses in the parking lot on the west side of the dam.

STOP 3 AND LUNCH. UNION CITY DAM

Leaders: Loren E. Babcock, Marilyn D. Wegweiser, Arthur E. Wegweiser, Scott C. McKenzie, and Alan Ostrander

NOTE: Hard hats are required here in order to examine the spillway walls.

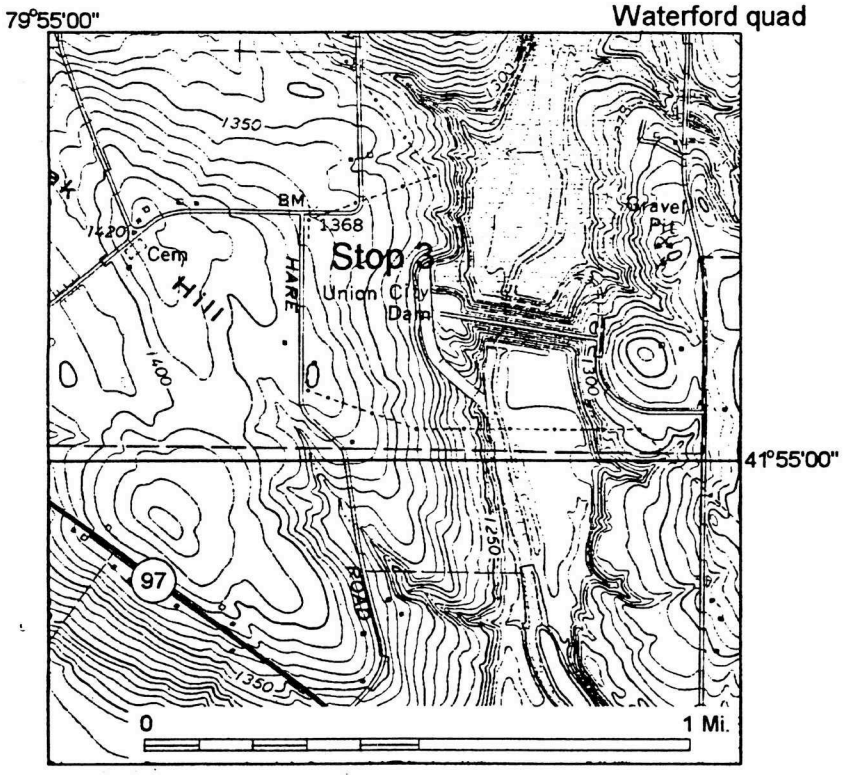

Figure 18- Location map for Stop 3.

The spillway to Union City Dam is located on the South Branch of French Creek in Waterford Township. Access is by a gravel road extending north off of U.S. Route 6, just north of Union City (Figure 18).

A large spillway channel with vertical walls has been cut by the Army Corps of Engineers adjacent to, and downstream of, the Union City Dam. Section exposed (Figure 19) extends through the upper part of the Chadakoin Formation (Upper Devonian) and the lower part of the Venango Formation (Upper Devonian). In places through the spillway, excellent bedding-plane exposures are present.

Approximately 120 ft (37 m) of the upper part of the Chadakoin Formation are exposed in the spillway to Union City Dam (Figure 19). The unit consists of medium gray to reddish-brown siltstones interbedded with gray, white, tan, and reddish-brown, quartz-rich sandstones. Sandstone interbeds range up to about 5 in. (12 cm) in thickness, and increase in number upsection. Sedimentary structures that are present include ripple marks (both symmetrical and, less commonly, asymmetrical ripple marks), flaser bedding, lenticular bedding, reactivation surfaces, mudcracks, and intraclastic conglomerates. Occasional shelly conglomerate beds are present. One prominent bed of convoluted siltstone is present approximately 29.5 ft (9 m) below the base of the Venango Formation (Figure 19). The contact with the overlying Venango Sandstone is transitional and, in this area, workers have placed the boundary in different locations. The Pennsylvania Geological Survey considers the base of the first thick sandstone bed in this succession to be the base of the Venango Formation. For mapping purposes, this is the most practical choice of a boundary in this area, and it is where we prefer to place it (Figure 19).

Body fossils collected from the upper Chadakoin at this site include brachiopods, pelmatozoan echinoderm columns, bivalves, gastropods, horseshoe crabs, and sponges (see Table 1 on p. 30). The trace fossil assemblage includes a variety of walking, resting, and dwelling traces

produced by a variety of organisms. Both horizontal and vertical traces are present. Some traces, such as *Protolimulus* (Figure 11) can be readily attributed to the activity of a trace maker (in this case, the horseshoe crab *Kasibelinurus*). Other traces, such as *Bifungites*, cannot be readily attributed to the activity of any particular trace maker, and may have been constructed by organisms having nonmineralized skeletons. Trace makers that lacked mineralized skeletons had limited preservation potential, and thus may never be known.

Approximately 45 ft (13 m) of the lower part of the Venango Formation are exposed in the upper part of the spillway (Figure 19). The unit consists of medium gray to reddish-brown siltstones interbedded with tan, white, gray, and reddish-brown, quartz-rich sandstones, quartz-rich conglomeratic sandstones, and intraclastic conglomerates. Sandstone intervals within the Venango Formation are much thicker than those present within the upper Chadakoin Formation; sandstone-dominated intervals range up to several meters in thickness. Sedimentary structures that are present include ripple marks, flaser bedding, lenticular bedding, reactivation surfaces, and intraclastic conglomerates. Fossils present in the Venango Formation include most of those present in the underlying Chadakoin Formation. Other than trace fossils such as *Protolimulus*, however, macroscopic fossils at this site are uncommon.

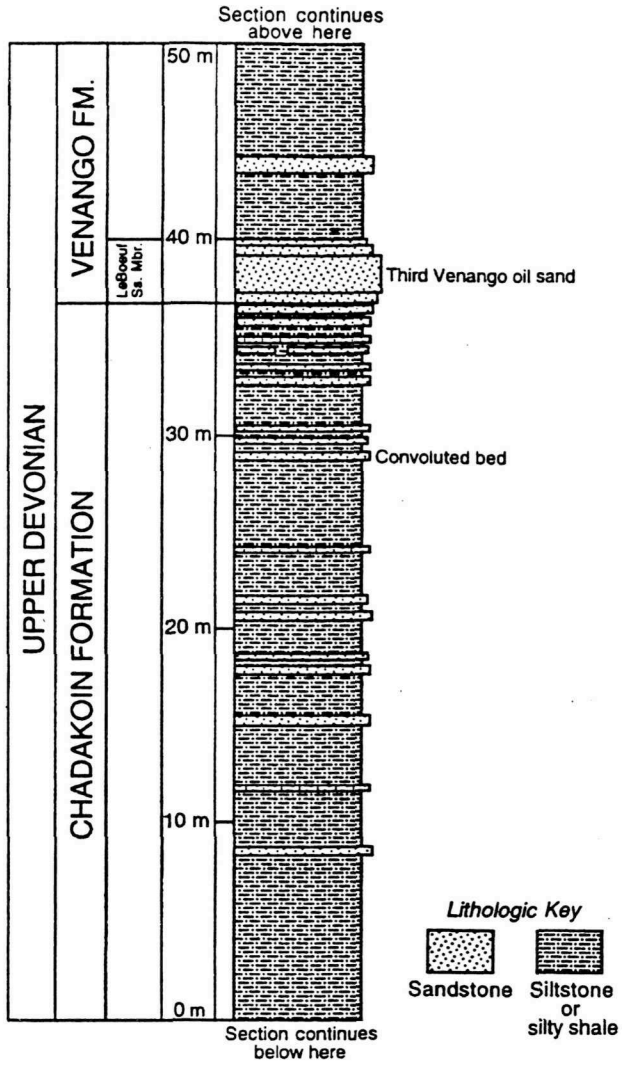

Figure 19- Columnar stratigraphic section of Upper Devonian strata exposed in the spillway of Union City Dam, Erie County, Pennsylvania.

Siltstones, sandstones, and conglomeratic sandstones of the Chadakoin and Venango Formations along the South Branch of French Creek are inferred to represent a series of related paleoenvironments ranging from shallow marine through estuarine and tidal flat settings (Babcock and others, 1995, this guidebook, p. 26). Regionally, these units record deposition in a coastal to marine shelf setting that was part of the Catskill delta complex of the Appalachian foreland basin. Streams emptied sediment westward into the foreland basin, and major shifts in sediment supply, accommodation space, and sea level produced dramatic facies shifts in a roughly east-west direction (by present-day coordinates). Redbeds present in the upper Chadakoin and lower Venango Formations suggest marginal-marine to nonmarine deposition at times. Mudcracks, which are present in places, suggest that some of the sediments were exposed to in-

termittent wet-dry conditions at the time of deposition. Those structures, together with the combination of flaser bedding, intraclastic conglomerates, and reactivation surfaces, suggest that some of these rocks were deposited in a tidal flat setting. Furthermore, the limited variety of marine fossils, the lack of complete crinoids, the presence of characteristic marginal-marine animals such as horseshoe crabs and the inarticulate brachiopod *Lingula*, and the preservation of nonmineralized arthropod cuticle, are consistent with deposition in a tidal flat setting, where salinity levels fluctuated between normal marine conditions, brackish water conditions, and fresh water conditions. The trace fossil assemblage, which includes *Protolimulus* and *Bifungites*, is also consistent with a tidal flat interpretation for some intervals exposed at this locality. Shell beds that are present in various places through the section at Union City Dam consist mostly of tightly packed brachiopod shells. They are probably the result of either storm deposition or wave washing that removed finer sediments.

The origin of the convoluted bed in the upper part of the Chadakoin Formation at this locality may be related to local slumping (such as rotation of unconsolidated sediments along the margin of a tidal channel. However, the extent of the bed within the spillway suggests that it has even greater lateral extent regionally. The bed may be due to the slumping of sediments following a syndepositional paleoearthquake.

Mileage Int	Cum	
		Leave Stop 3 and **return to** Middleton Rd.
0.6	87.2	**Turn right** (south) onto Middleton Rd. and return to PA Rt. 97.
0.7	87.9	**Turn right** (west) onto PA Rt. 97 and **proceed** back to the hotel.
5.1	93.0	Junction of PA Rt. 97 with US Rt. 19. **Continue** north on Rts 97/19.
1.4	94.4	Junction of Rts 97/19. **Turn right** and **proceed** north on PA Rt. 97.
8.7	103.1	**Arrive back** at the Quality Inn. End of Day One field stops. Enjoy the banquet and the evening. Put on your dancing shoes and head down to Boot Scooter's Dance Hall in Waterford.

Guidebook for the

63rd ANNUAL FIELD CONFERENCE OF PENNSYLVANIA GEOLOGISTS

GEOTECTONIC ENVIRONMENT OF THE LAKE ERIE CRUSTAL BLOCK

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October 1- 3, 1998

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Cover: Eminent structural geologist, Dr. Eberhardt Hedditt, a giant in his field (nyuk, nyuk), stands firm in his refusal to accept the fact of tectonic deformation in northwestern Pennsylvania.

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