BIOCLASTIC CARBONATE UNITS IN THE CATSKILL CLASTIC WEDGE

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INTRODUCTION

This trip we will visit two quarries in northern Pennsylvania (Fig. 1) which expose thick carbonate units nearly unique in the "Catskill delta". Our purpose is to examine these units and to discuss their origin, which in many respects remains enigmatic despite considerable study.

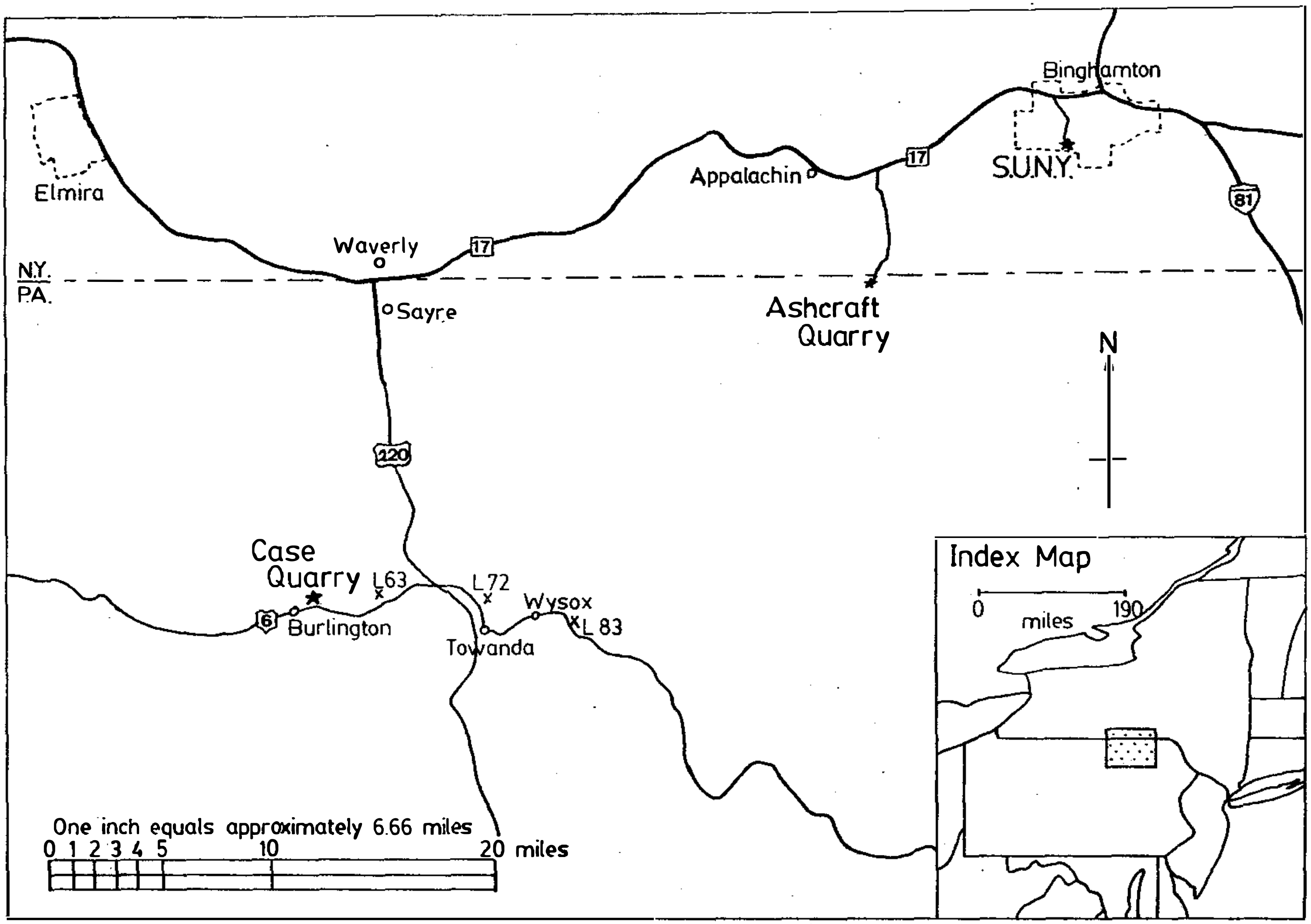
Each of us has contributed to this guidebook in a different manner. All of us have examined both quarries in varying levels of detail. Woodrow and Bottjer measured sections in the Case quarry and considered the trace fossils and petrography there. Minero measured the Ashcraft quarry sections. Enos and Woodrow have supervised the work of several students in both areas.

STRATIGRAPHIC CONTEXT OF THE CARBONATE ROCKS

Rocks seen in the two quarries are part of the Catskill clastic wedge (Woodrow, 1968). Carbonate-rich rocks are unusual in this sequence which is typified by sandstones, siltstones, and shales. Both units were worked initially for agricultural lime,and quarries were later opened because the carbonates provide the best material for riprap available for many miles.

Stratigraphic relationships within the Catskill clastic wedge have intrigued geologists since the middle of the nineteenth century. The major outlines of the stratigraphy have long been known and great strides have been made recently toward an understanding of the sedimentology. Uncertainties exist in both areas, however, even after 100 years of concerted effort by several generations of geologists. That this is so is understandable, especially in northern Pennsylvania, considering that:

a. The rocks are not well exposed, a limitation only partly offset by a few exploratory gas wells drilled in the region.
b. The rocks are gently folded and are broken by small faults.
c. The rock sequence is subject to major facies change over short distances.
d. Trends of facies change, local structure, and regional dip all differ within this area (Fig. 2).



Binghamton
S.U.N.Y.
Elmira
Appalachin
17
81
Waverly
N.Y.
PA.
Sayre
Ashcraft
Quarry
N
120
Case
Quarry
L63
L72
Wysox
L 83
6
Burlington
Towanda
Index Map
0
miles
190
One inch equals approximately 6.66 miles
0 1 2 3 4 5 10 20 miles

Stratigraphic disclaimers notwithstanding, it is possible to arrive at some reasonable judgments about the stratigraphic position of these carbonate units based on physical stratigraphic techniques (Woodrow, 1968; Woodrow and Nugent, 1963). The biostratigraphy of the carbonate rocks has not been studied in detail.

The limestone unit at the Ashcraft quarry apparently occurs at the horizon of or just above the dark Corning Shale (Rickard, 1975). The carbonate at the Louis Case quarry is part of the Luthers Mills Coquinite of Willard (1936), a member of the Towanda Formation (Woodrow, 1968); the quarry is cut into rock approximately 30 to 50 m above the Dunkirk Shale (Rickard, 1975; Woodrow, 1968). It is, thus, considerably younger than the limestone at Ashcraft quarry (Fig. 3). Based on these rock-stratigraphic assignments, the Ashcraft limestone is of mid-Frasnian age and the Luthers Mills Coquinite is of earliest Famennian age.

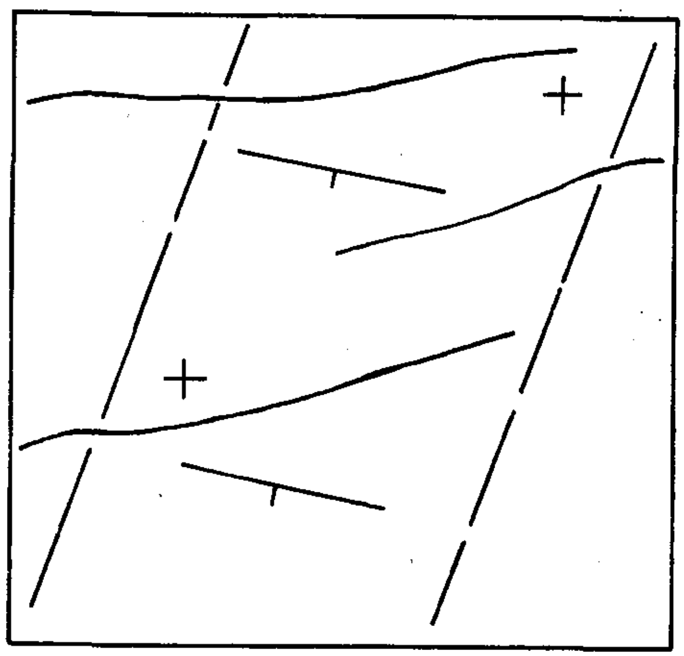
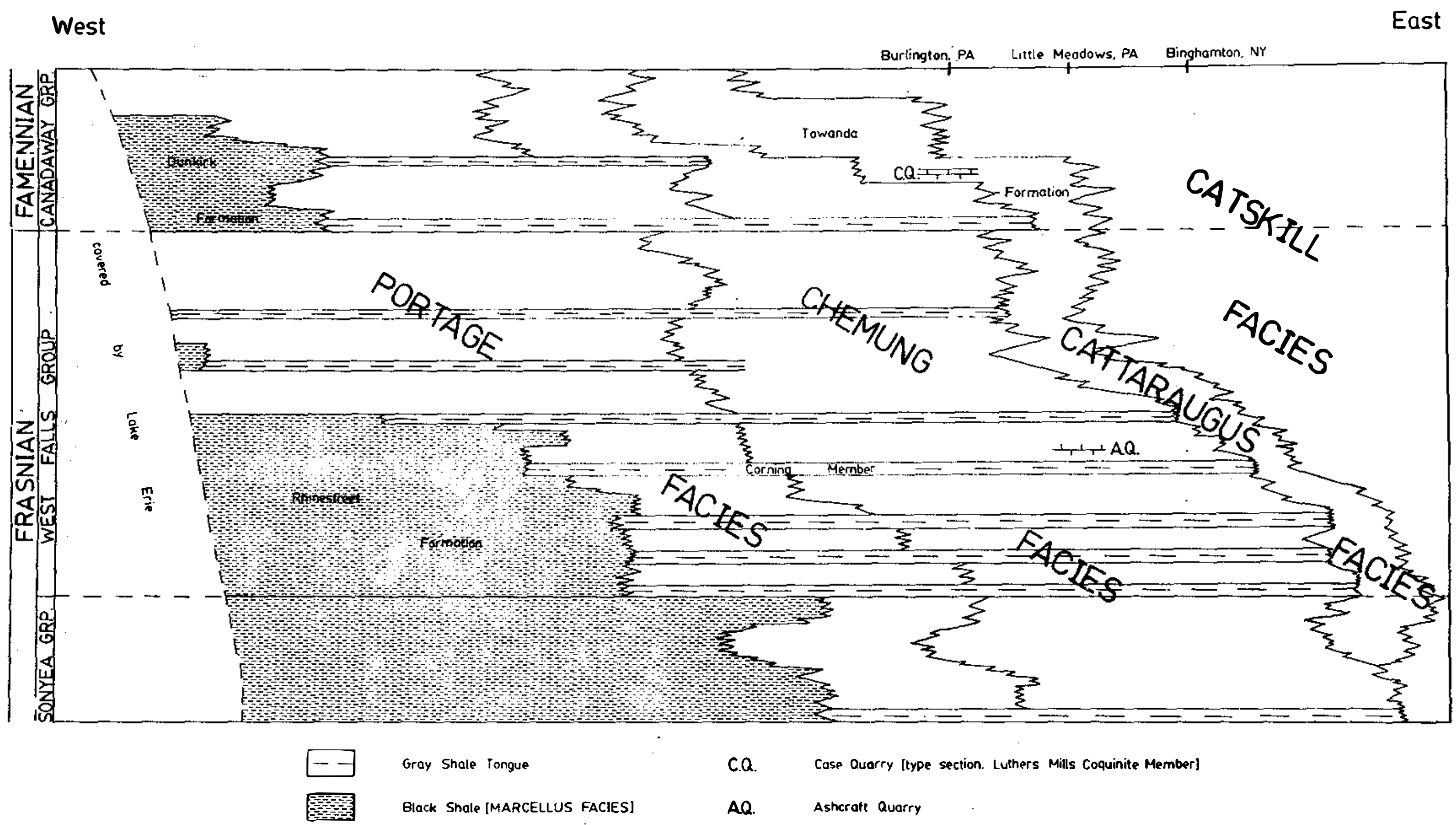


Figure 2. Structural, facies, and regional basin trends near the carbonate quarries (shown with crosses). Facies trends: dashed lines; anticlinal axes: solid lines; basin trend: strike and dip symbols.

◂ Figure 1. Location map showing Ashcraft and Case quarries. Localities L63, L72, and L83 are outcrops of Luthers Mills Coquinite from Woodrow (1968).



Upper Devonian Facies Relationships

Southern New York and Northern Pennsylvania (modified from Rickard, 1975)

ROCKS AT ASHCRAFT QUARRY

The quarry is located on the northwest-facing slope of a hill east of the village of Little Meadows, Pennsylvania (Fig. 1). Rocks exposed in the quarry are part of the West Falls Group and they probably lie less than 15 m above the Corning Shale Member within the Gardeau Formation (Fisher and others, 1970; Rickard, 1975). Local dip is generally southwest at about 1:50 (100 feet per mile). The trend of the quarry face is 65 degrees. The quarry wall is approximately 15 meters high and 200 meters long.

Three subdivisions of the rock sequence are readily apparent (Figs. 4 and 5). A basal unit made up of sandstone and shale is exposed in the sump pit at the northeast end and patchily on the quarry floor and walls. This is overlain with an erosional contact by the limestone unit that is exposed throughout the quarry. The upper unit is in sharp contact with the limestone and extends to the top of the quarry wall for a thickness of 10-12 meters. It is interbedded shale, siltstone, and sandstone.

Basal Unit

As seen in the sump pit (Fig. 5), this unit is greenish-gray shale and lenticular siltstone overlain by gray, medium-bedded sandstone with trough cross bedding. Horizontal burrows and small plant fragments are common in the silt and shale. Crinoids, brachiopods, large carbonized wood fragments, and intraclasts form coarse-grained lenses in the sandstone. Shallow trough cross-beds indicate paleocurrents toward 175°. Asymmetric straight-crested ripples (paleocurrent azimuth 120°) exposed on the quarry floor were locally eroded and reformed into linguoid ripples directed 290°, showing current reversal.

Limestone Unit

The quartzose carbonate unit is the quarryman's objective and the unit of major geologic interest. It varies in thickness from about 5.5 m in the center and eastern part of the quarry to 3.5 m toward the west. Core drilling on the hill south of the quarry demonstrates considerable thickness variation (some possibly the result of glacial or preglacial erosion) with perhaps a general thinning trend toward the southwest (Figs. 6 and 7). With the limited number of core holes and the till cover, the geometry of the body is conjectural, particularly toward the southeast. Previous workers (Krajewski and Cuffey, 1976; Bowen, 1978) have concluded that the unit is a N-S elongated mound confined within the limits of the hill. This cannot be verified from the existing data and must therefore be regarded as only one possible configuration. A tabular body—with internal wedge-shaped units—truncated by erosion and covered by till is another possibility.

< Figure 3. Upper Devonian facies relationships (from Rickard, 1975).

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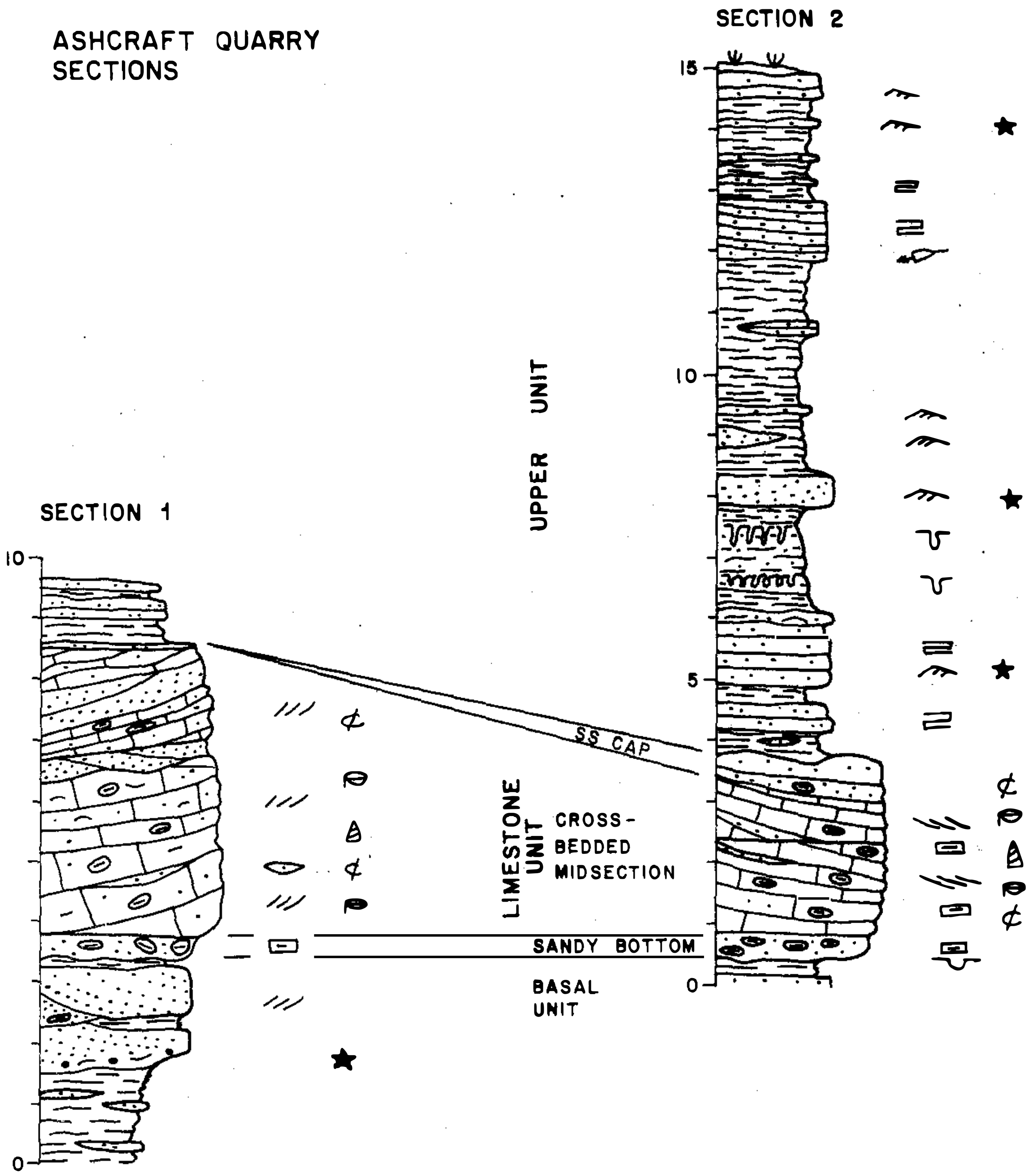


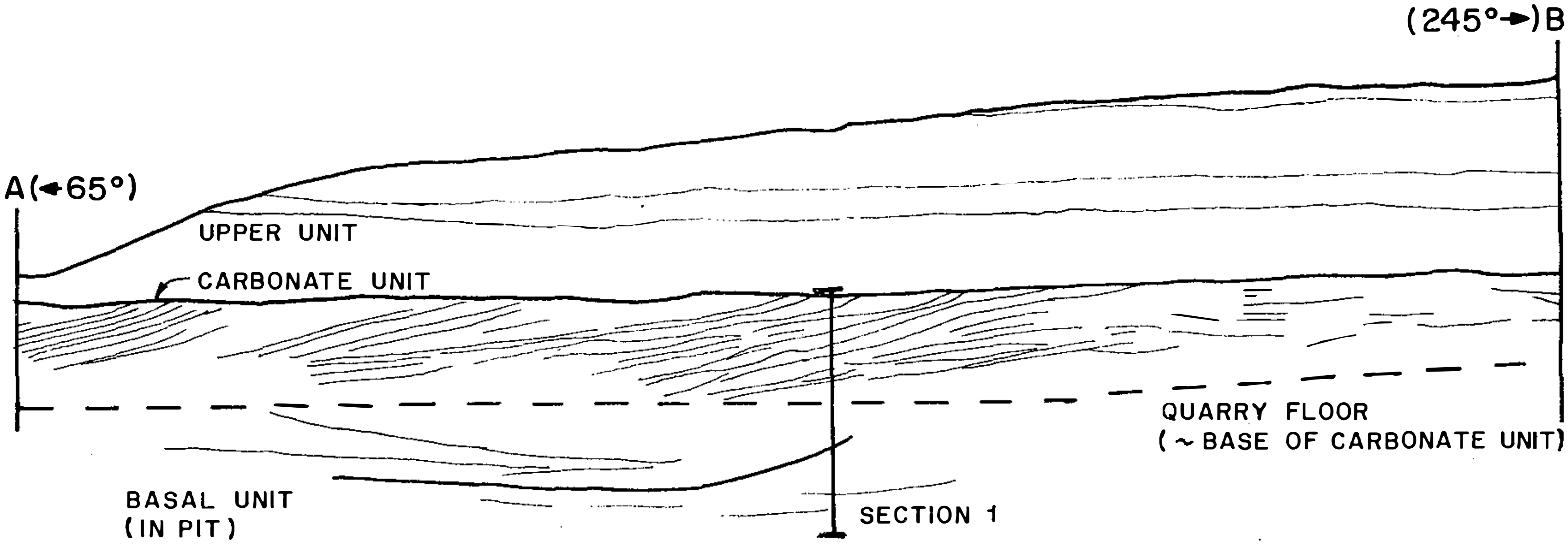
Figure 4. Sections at Ashcraft quarry, measured by Minero. Locations are shown in Figure 5. For symbols see Figure 10.

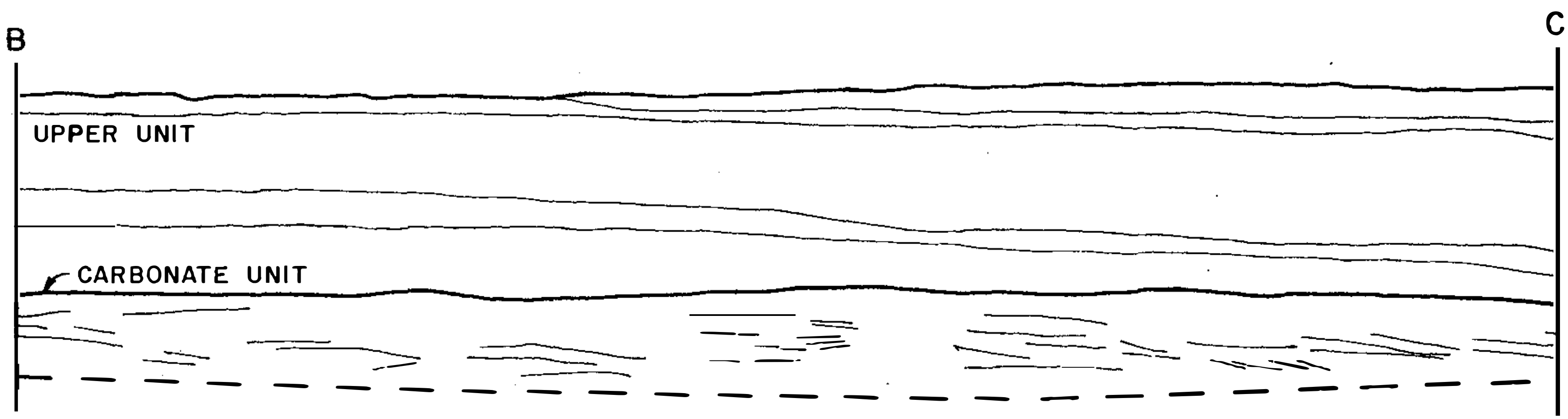
In general, the limestone unit consists of quartzose, skeletal-fragment lime grainstone and skeletal quartz sandstone. Grain size fines upward in the unit. Top and bottom contacts are sharp. Three subdivisions can be recognized, a sandstone bottom, a cross-bedded midsection, and a thin sandstone cap.

Sandstone Bottom. Medium- to coarse-grained, lithoclastic calcareous sandstone, generally less than 60 cm thick, overlies the basal unit with a sharp, apparently erosional, contact. Locally the base of the sandstone is load deformed and small, truncated shale diapirs occur at the top of the underlying unit. In addition to quartz sand and some shell fragments, the sandstone contains numerous large, gray shale clasts and reworked ankerite $Ca(Mg, Fe)(CO_3)_2$ nodules (Minero, unpub. report). The nodules weather to an orange-brown oxide (?) which stains the rocks in this subdivision. Plant fragments, locally permineralized by pyrite, are also common. Low-angle cross bedding is locally visible.

Cross-Bedded Midsection. The bulk of the limestone unit is cross-bedded, quartzose, skeletal-fragment lime grainstone. Trough and wedge-shaped cross-bed sets are up to several meters thick, although most are tens of centimeters thick. Reworked ankerite nodules, shale clasts, and carbonized plant fragments are all common. The ankerite weathers to an orange-brown oxide (?) to produce a mottled appearance against the light-gray background. Rusty yellow streaks on the weathered surface mark the position of large plant fragments, most of which are partially pyritized, some with exquisite preservation of detail. Highly abraded shell fragments, quartz, and some feldspar comprise most of the sand-sized grains of the rock. The quartz is fine- to medium-grained and appears angular, but quartz over-growths and etched margins filled by calcite suggest that original grain shape has been highly altered. Most skeletons are abraded fragments and are also diagenetically altered to calcite-filled molds or neomorphic calcite, so that few can be identified except by general shape. Recognizable fragments include brachiopods, gastropods, bivalves, crinoids, and fish plates. Shelly portions of the carbonate unit are cemented by medium- to coarse-grained calcite spar; quartzose portions have some clay matrix and fine-grained carbonate. Modal analyses of Bowen (1978) indicate an average of about 80 percent carbonate, including cement, sparse matrix, local replacement dolomite, and more than 30 percent fossil fragments.

Calcareous quartz sandstone is interspersed with the limestone on scales ranging from small lenses, representing isolated ripples or dunes, to the largest cross-bed sets. Inter-leaving of large wedge-shaped units is best seen at the east end of the quarry and in the northwest corner. Quartz-sandstone wedges appear to laterally replace limestone ones at both locations, suggesting that the limestone-dominant rocks are indeed limited to a central "mound" (Krajewski and Cuffey, 1976; Bowen, 1978), but more lateral control is needed. Lateral-accretion bedding of the wedges dips toward the east at the east end of the quarry and a northwest-directed mode is found toward the west end (Fig. 8A). Throughout the quarry, however, smaller scale troughs open toward the west (Fig. 8B).


(245°→)B
A(←65°)
UPPER UNIT
CARBONATE UNIT
QUARRY FLOOR
(~ BASE OF CARBONATE UNIT)
BASAL UNIT
(IN PIT)
SECTION 1


B
C
UPPER UNIT
CARBONATE UNIT

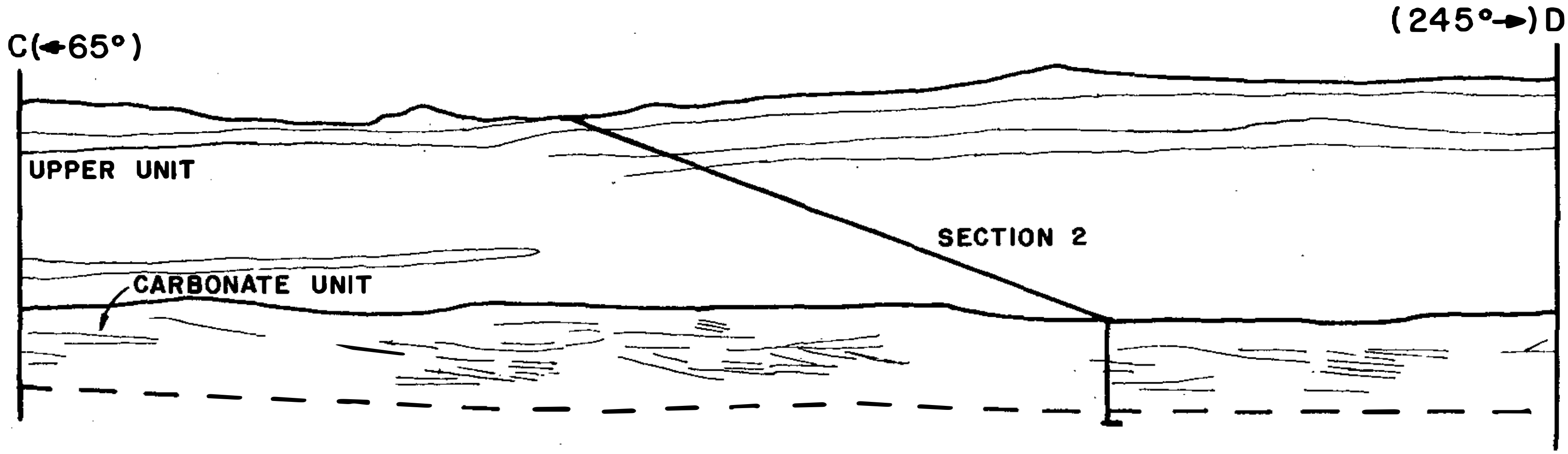


Figure 5. Sketch section of the high wall (SE) of Ashcraft quarry from a photo mosaic by Minero. Sequence of panels from top (A-B) to bottom (C-D) join left to right as indicated by matching letters. Scale is inexact because of photographic distortion; each panel is about 65 m wide; maximum height is about 15 m. Location of sections in Fig. 4 are indicated.

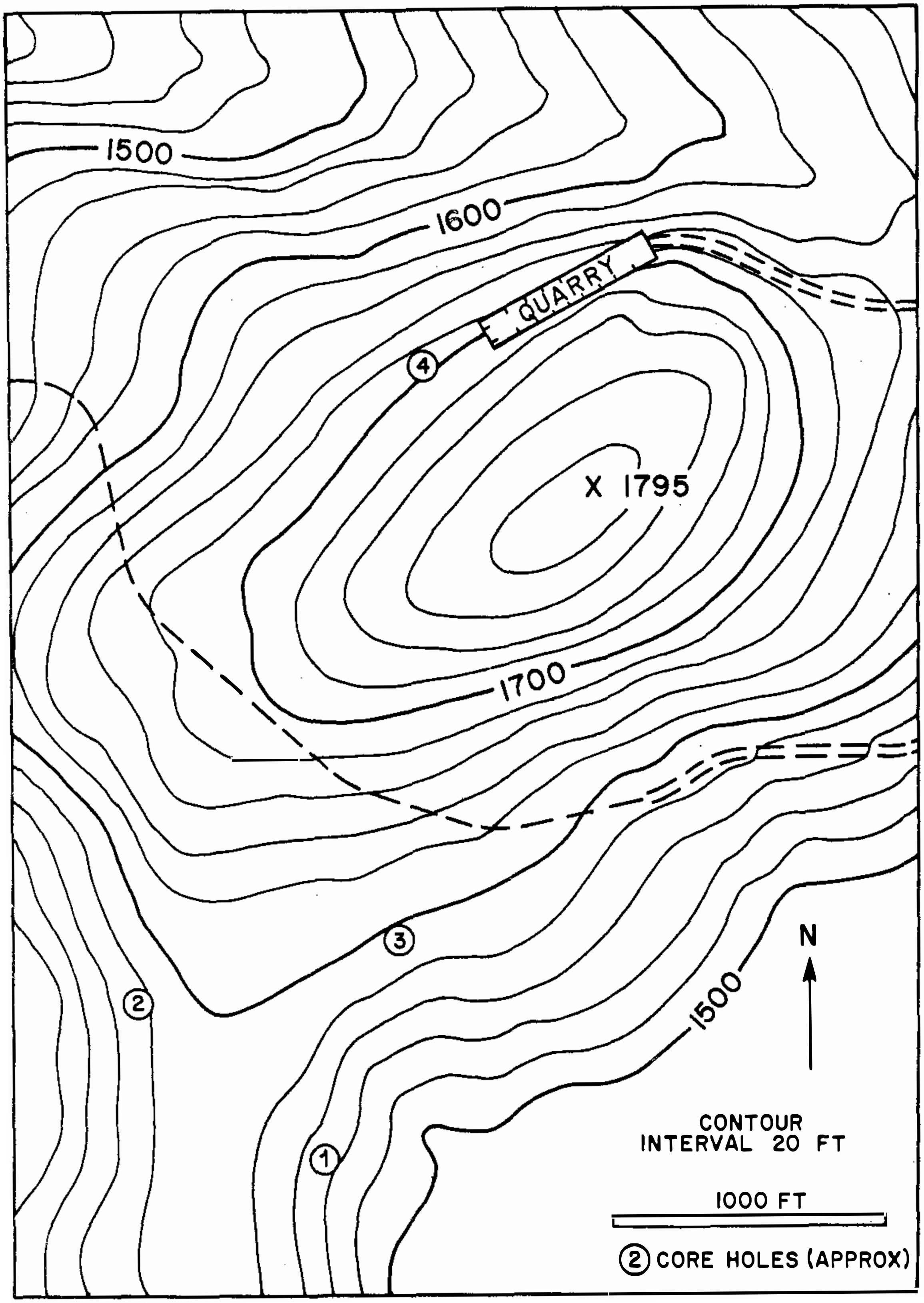


Figure 6. Ashcraft quarry area, showing approximate location of core holes (from Krajewski, unpub., and Ashcraft Excavating Company files). Contour base from Friendsville 7-1/2 min. quadrangle.

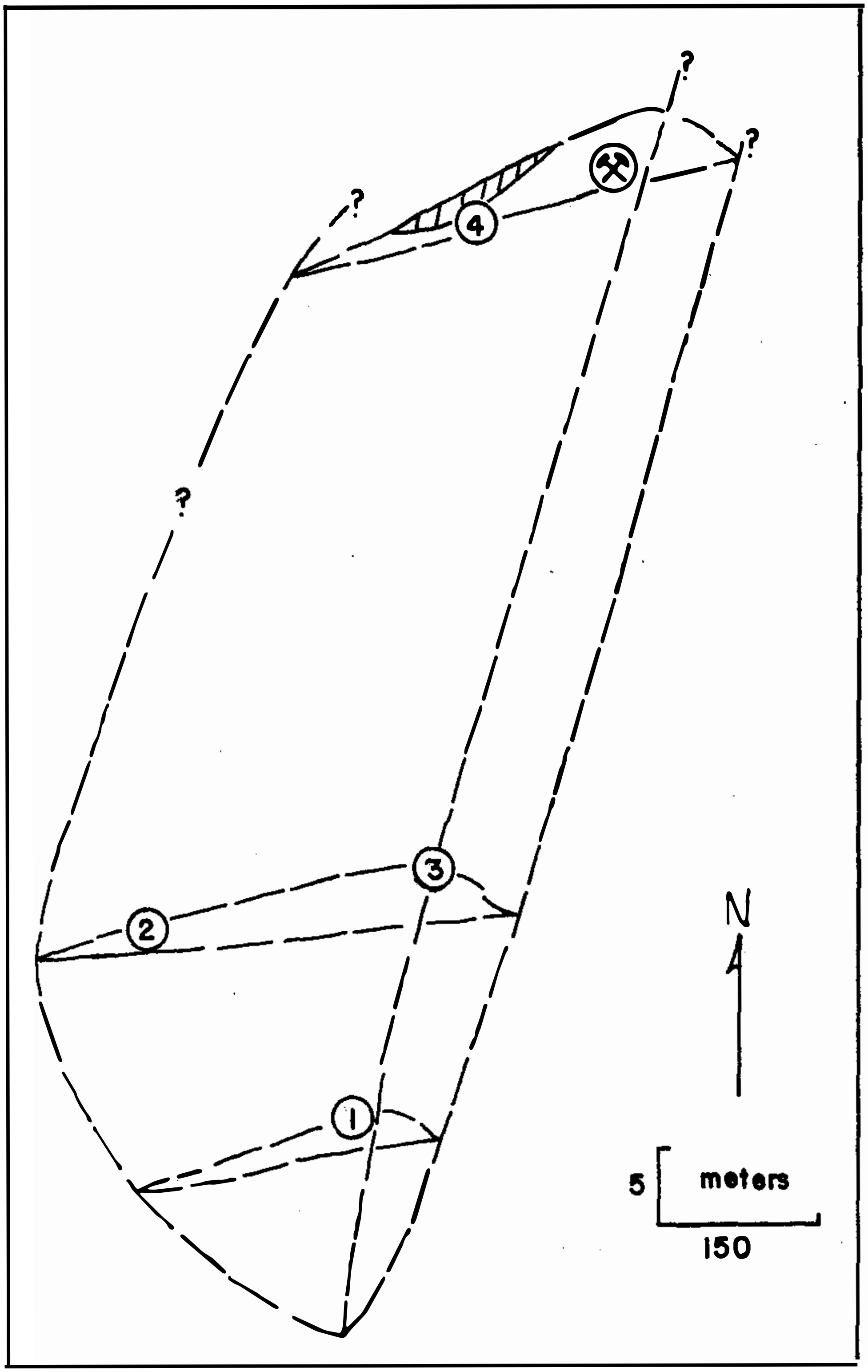


Figure 7. One possible reconstruction of the limestone body: The Wind and a Prayer Model. Location of core holes numbered. Till rests on carbonate at no. 4; erosion is assumed. Northward extent of the body is obscured by erosion; southward limit is also conjectural. Core data from Ashcraft Excavating Co. files.

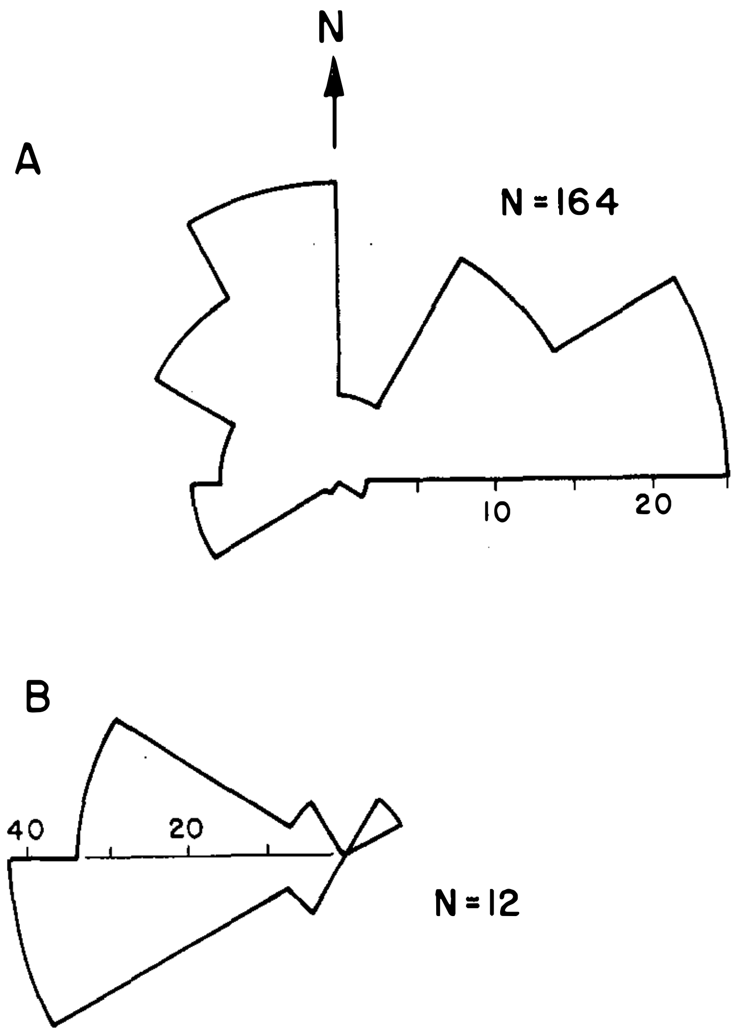


Figure 8. Paleocurrent measurements from carbonate unit in Ashcraft quarry. Scales are percentage of total measurements (N) in 30^{o} intervals. A. Dip directions of 164 cross-beds, measurements by S. A. Krajewski (unpub. data). These are primarily large-scale lateral-accretion bedding, although some trough limbs are included. The east-directed mode is primarily from the east end of the quarry, the NNW mode is from the northwest corner, and the weak WSW mode is from the southwest corner (Krajewski, written comm.).
B. Axial trends of 12 trough cross-bed sets.

Sandstone Cap. A light-gray quartz sandstone that weathers dull brown discontinuously veneers the limestone unit. Although the contact with the cross-bedded midsection locally appears gradational, it also bevels inclined accretionary wedges (Fig. 5). Cross-bedding is generally not apparent within the sandstone, and there are hints of bioturbation that may explain its absence and the gradational lower contact. However, the top of the unit is wavy in many places, and a large bench cut on this unit at the southwest end of the quarry displays numerous nearly straight-crested dunes formed by paleocurrents, mainly toward 110°. The dunes are ornamented by wave ripples, and locally by current ripples, whose variable orientations show that the dune forms channelled subsequent flow. Trace fossils are also common on this surface, including very large horizontal tubes (to 5 cm in diameter) and clusters of long curving tubes.

Identifiable fossils are rare in the sandstone cap; they include a few brachiopods and gastropods. Some large fish-bone and plant fragments have been recovered.

In summary, the limestone unit consists of wedge-shaped cross-bed sets of skeletal lime grainstone and quartz sandstone sandwiched between two thin layers of sandstone. Detrital ankerite nodules, plant fragments, and fish bones are present throughout, but decrease in abundance upward as grain size generally fines. The ankerite nodules range from 0.5 to 7 cm in diameter and consist of micritic to mm-sized carbonate crystals that generally coarsen toward the margins of the nodule in a crudely concentric pattern. One nodule analyzed contained 8.8 percent iron oxide. Most nodules are rounded and they are locally size sorted. Quartz grains within the nodules are more angular, much finer, and less numerous than in the surrounding rock. Thus, the nodules are clearly rewored (Minero unpub. report). Plant fragments are mainly woody trunk material. Some fish bones have been tentatively identified with the arthrodire, Dinicthys (Fig. 9; R. Caprio, unpub. report). The preserved invertebrate fauna consists mainly of brachiopod fragments, gastropod molds, and rare bivalves and crinoids. Burrows are not visible throughout most of the unit, especially in the cross-bedded portion, but are abundant on the top surface. Cross-bedding in the large-scale sets indicates lateral accretion toward the east and northwest (Fig. 8A), away from the center of the quarry. Depositional relief is clearly indicated with some truncation probable at the top of the unit (Fig. 5). Trough cross-bedding is directed westward throughout (Fig. 8B). Preserved dunes were formed by southeasterly currents and ripples are quite variable in orientation.

Upper Unit

Dark-gray and olive-brown shales and mudstones and light blue-gray, fine- to medium-grained sandstones make up the remainder of the quarry high wall (Figs. 4 and 5). Individual sandstones are several centimeters to a meter thick and vary in thickness across the quarry. Many sandstones are lens-shaped over tens of meters suggesting current bedforms of low amplitude. Most sandstones exhibit either ripple cross-stratification or horizontal lamination. Shallow troughs or channels are visible in a few beds. Large load casts or flow rolls deform some channels. The shales

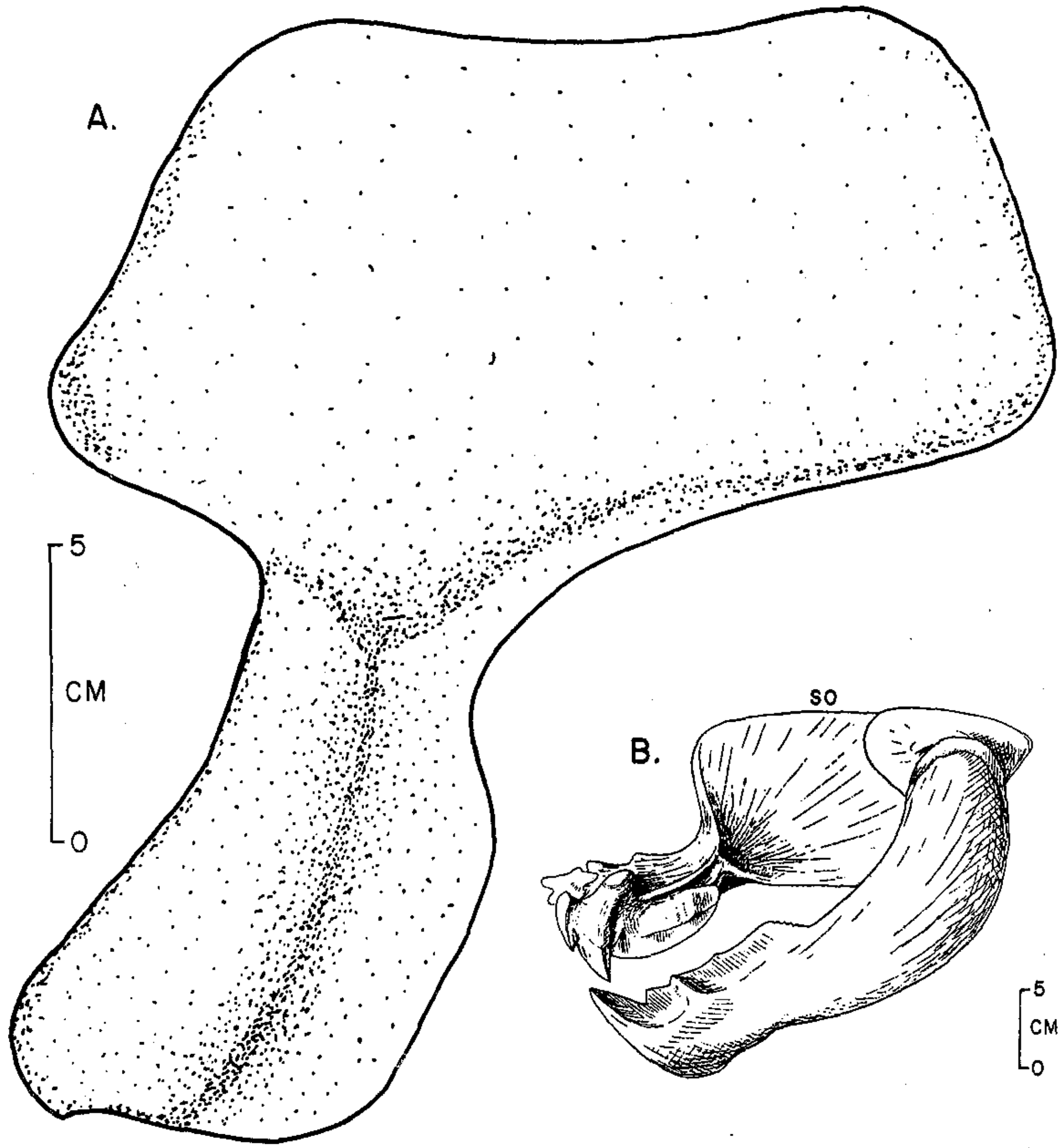


Figure 9. Fish plate from Ashcraft quarry. A. Sketch of the plate, probably the suborbital bone of the arthrodiran placoderm, Dinichthys. B. Diagram of the jaw of Dinichthys showing an internal view of the suborbital (SO), from Heintz (1931, p. 229). Sketch and identification are by Richard Caprio (unpub. report, 1978).

and mudstones are bioturbated, locally to the degree that stratification is totally disrupted and sand-shale layers are homogenized (Fig. 4). Trace fossils include copious trails on bedding surfaces and Skolithus-like vertical tubes. Few body fossils are found except in thin brachiopod-crinoid coquinites at the base of some sandstones. A few lingulid brachiopods have been found in float that probably came from this interval. Plant and fish fossils are relatively rare. Grooves and faint flutes on the base of one sandstone indicate average paleocurrent directions of 298° (5 readings). Ripple cross-lamination is generally west directed and several sandstone beds appear to thin westward.

ROCKS AT LOUIS CASE QUARRY

The quarry is on a south-facing slope located at the north side of U.S. Route 6, one mile east of the village of Burlington, Pennsylvania (Fig. 1). It was opened recently to exploit the Luthers Mills Coquinite as riprap. An older, smaller quarry, about 100 m to the east of the Case quarry, was opened in the 19th century to exploit the coquinite for agricultural lime and is the type locality of the Luthers Mills Coquinite (Willard, 1936).

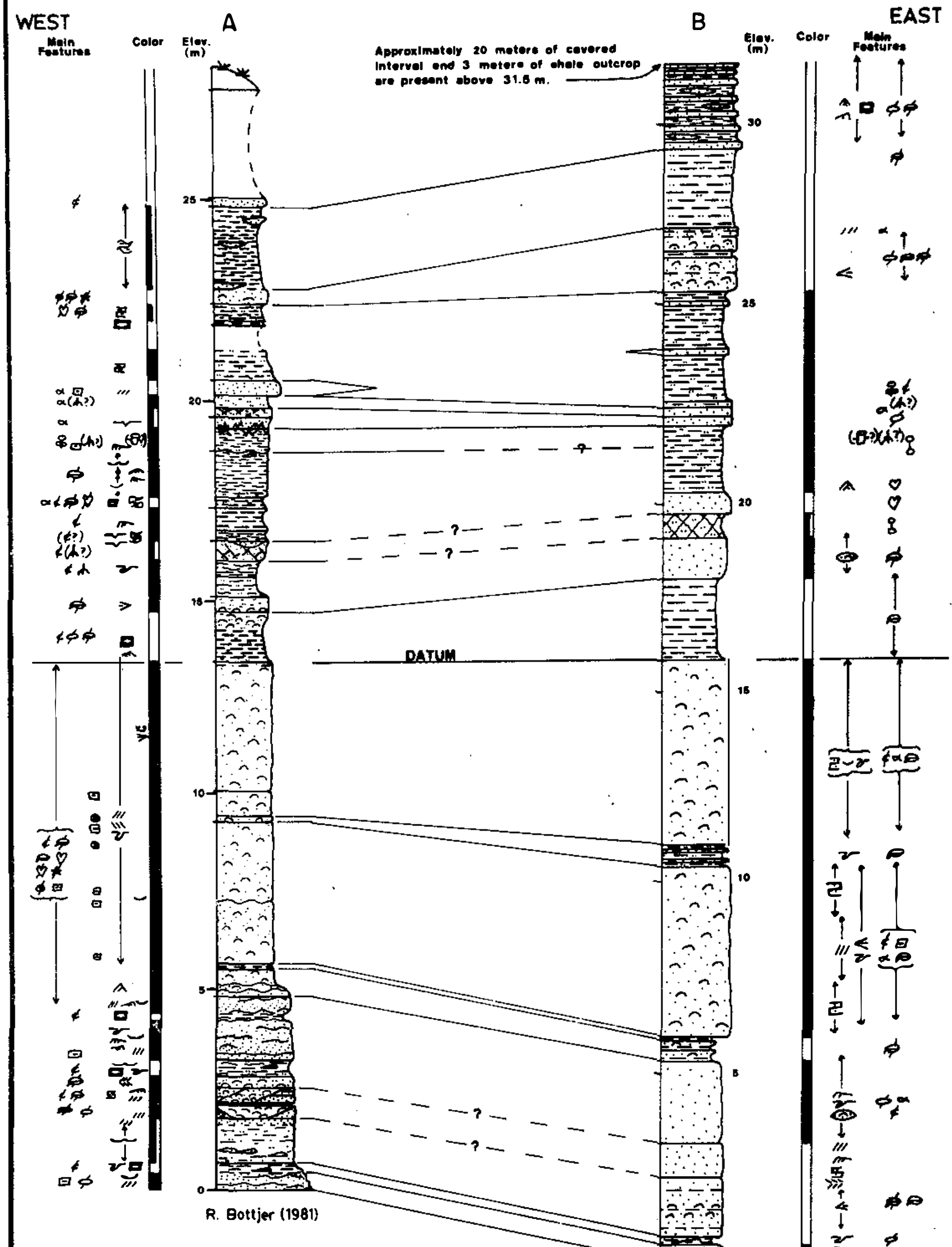
Stratigraphic placement of the quarry sequence (Fig. 3) has it in the Upper Devonian Towanda Formation (Woodrow, 1968) or the Lock Haven Formation of Pennsylvania useage (T. M. Berg, Pennsylvania Geological Survey, pers. comm., 1981). The thick coquinites were referred to by Willard (1936) as the Luthers Mills Coquinite, a distinctive, discontinuous rock unit which extends from Burlington at least as far east as the hills east of the Susquehanna River at Towanda (Fig. 1).

Within the quarry, the rocks are divisible into the Luthers Mills Coquinite at the base and the overlying shales and sandstones (Fig. 10). The base of the Luthers Mills is beneath the quarry level, but its sharp upper contact is clearly visible.

Geologic structure in the region is more pronounced than at the Ashcraft quarry. Locally the dip is north at 7° on the north limb of the Towanda anticline.

Luthers Mills Coquinite. This striking rock unit is at least 16 meters thick (the basal contact is not exposed) and of that thickness more than 80 percent is shell-rich. Strata are red or greenish gray with broken, abraded, or, rarely, whole shells arrayed in layers tens of centimeters thick. Most beds persist for tens of meters with sharp contacts. Cross-stratification and clay-draped ripples (flaser bedding) are common. Sandstone and mudstone beds are more common in the lowest 5 m of the exposure.

Sedimentary structures include plane bedding; wave, interference, and current ripples; cross-stratification; and load casts. Troughs of cross-strata open toward the west (260° to 310°) and ripple asymmetry is bimodal (Fig. 11). In some troughs, ripples were developed by paleo-currents perpendicular or opposed to those which formed the troughs.



Scale: 1 inch equals 25 meters

Legend: see figure 4

Colors ▌Red ▌| Partly Red || Non-Red

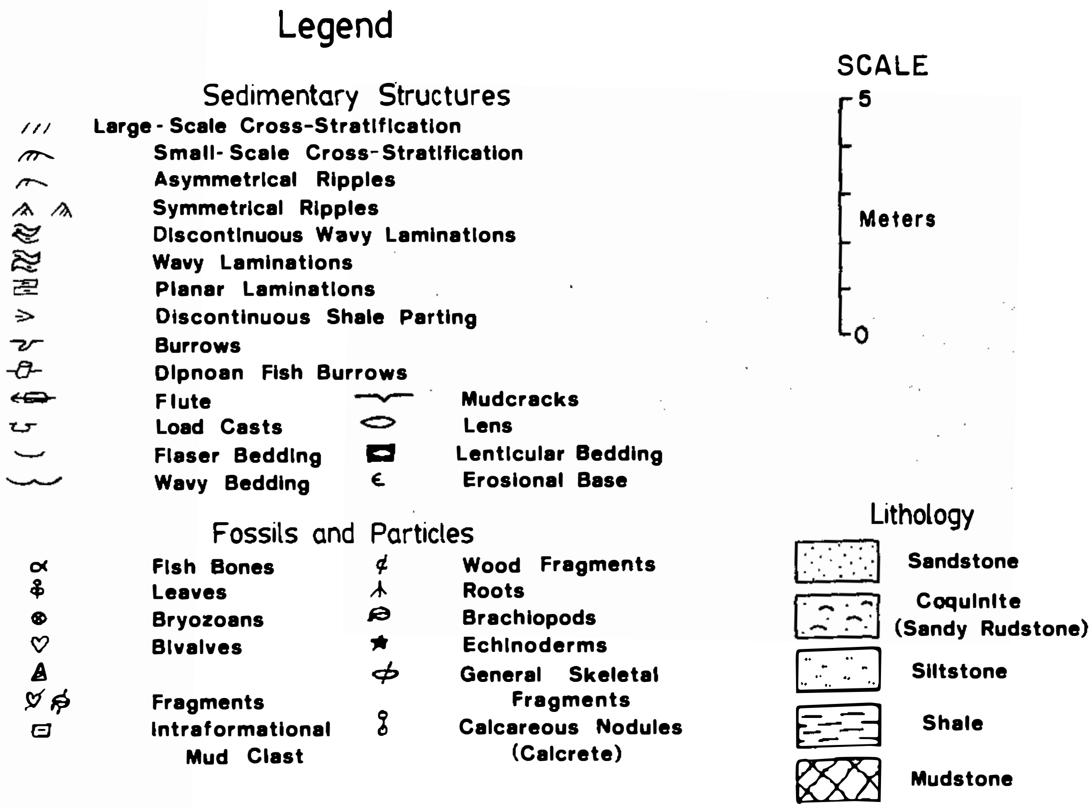


Figure 10. Measured sections from Case quarry. A is from the west center of the quarry; B is at the east end. Symbols for measured sections (including Figure 4) are above.

Quartz, rock fragments, and shells are the framework elements in these rocks (Table 1). Matrix consists of red hematitic mud and fine carbonate. Cement is predominantly calcite. Dolomite rhombs in the matrix and in internal skeletal cavities filled with red mud constitute several percent of some shelly samples.

Table 1. Major Components in Coquinite at the Louis Case Quarry, in Volume Percent.

	Shell-rich Rock	Shell-poor Rock
Quartz and chert fragments	14.7	21.5
Rock fragments	21.3	37.5
Fossils	32.9	9.7
Matrix and cement (carbonate)	17.4	18.5
Red mud	13.6	12.9

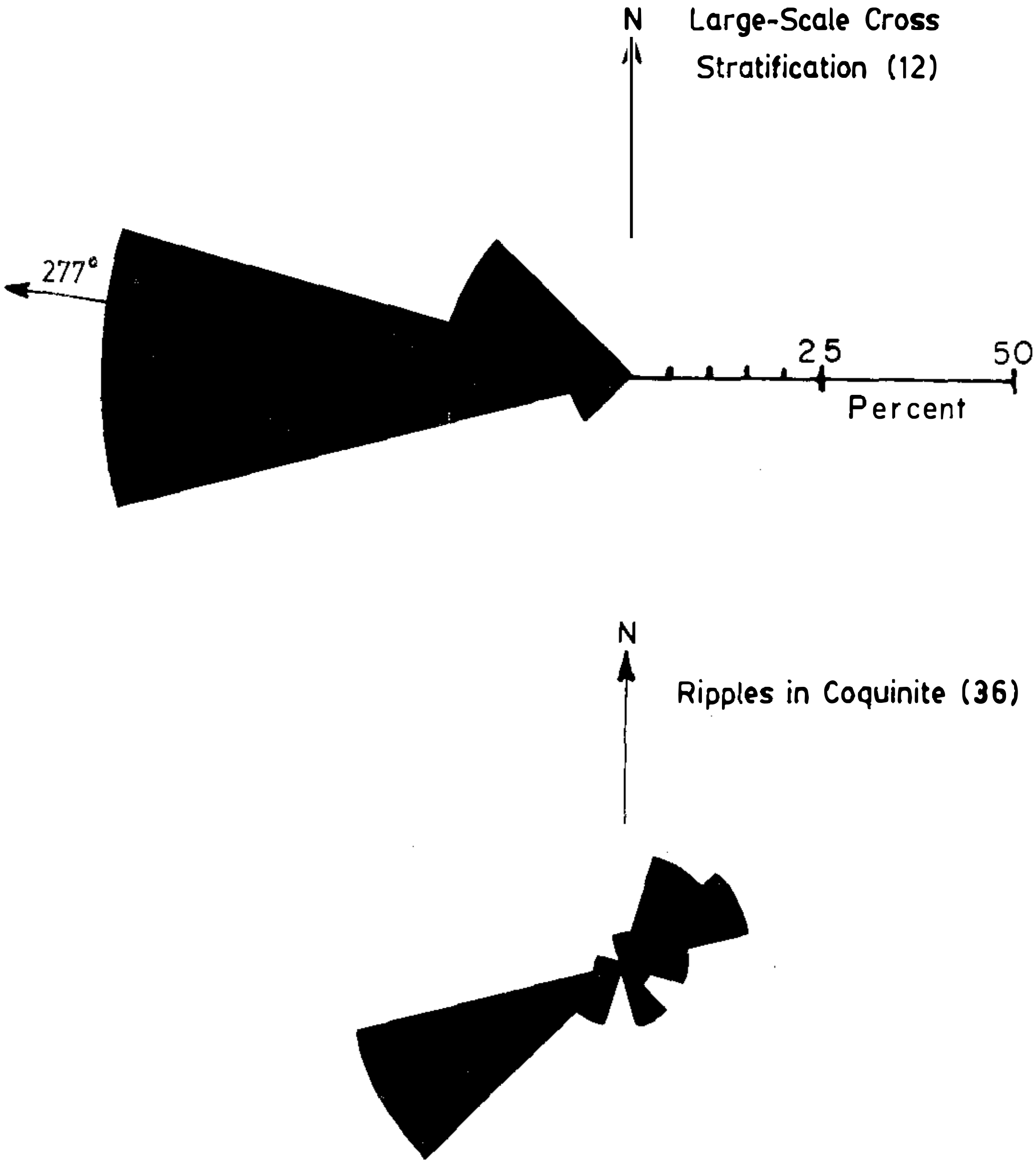


Figure 11. Paleocurrents from Case quarry. Scales are in percentage of total measurements in 30° intervals. A. Large-scale cross stratification, 12 readings, from the Luthers Mills Coquinite. Most readings are axial trends of troughs; the remainder are dips of cross-beds. B. Transport directions indicated by 36 asymmetrical ripple marks.

The hematite occurs as thick rims on well-rounded grains and locally partially replaces some grains. It is the pervasive coloring agent in the matrix. Two matrix samples contained 7 and 11.8 percent iron oxide but an average of only 4.4 percent Fe_2O_3. Rock fragments are mostly red and green shale, gray and green mudstones, and a variety of low-grade metamorphics. Many are rimmed with hematite. Fossils found in the coquinite are commonly broken and abraded. However, articulated brachiopods are not uncommon, and both colonies and individual branching bryozoans were found in two layers (about 9 m in Fig. 10A). Bivalves, crinoids, and bone fragments are less common. Many of the zooceia in bryozoa have been filled with hematite-rich mud which contains tiny rhombs of dolomite. Similarly, some bone and crinoid fragments have been replaced or infiltrated by hematitic mud in which dolomite rhombs are found.

The fauna represented in the coquinite is composed mainly of shelly invertebrates. The most common brachiopods are *Cyrtospirifer* sp. and *Athyris* sp.; they far outnumber the other fossils. Among the others are brachiopods, *Camarotoechia* sp. and *Cryptonella* sp.; bivalves, *Grammysia circularis*, *Nuculoidea corbuliformis*, *Eoschizodus chemungensis*, (Bottjer, 1981); and bryozoans, *Leioclema* cf. *subramosa*, *Eridotrypella parvulipora* and a bifoliate cryptosome (R. J. Cuffey, written comm., 1981). The bryozoans occur as single specimens, as colonies up to 70 cm across and 10 cm high, and as binders or encrusters enclosing other fossils. Trace fossils are a distinctive feature of the coquinite (D. B. Hutchinson, unpub. report, 1981). Two distinctive trace fossils are shown in Fig. 12; one (12B) is certainly a feeding trace. Other trace fossils found include: straight vertical burrows, U-shaped vertical burrows (rare), resting traces, *Cruziana* (?), tracks and trails. In many examples, activities of the trace-forming organisms have apparently moved shells enough to give beds a chaotic fabric.

Overlying Shales and Sandstones. The rocks extending about 15 m from the coquinite to the top of the quarry wall are a complexly interbedded sequence of gray-green silty shales; red silty shales; and red or green, lenticular, muddy sandstones and siltstones. Several thin shell-rich beds are found above the thick coquinite (Fig. 10). Small *in situ* carbonate nodules are found in red mudstones and shales at 19.5 and 21.5 m (Fig. 10B) along with some poorly preserved mud cracks. Vertical and inclined tube-casts up to 5 cm in diameter were found at 19 m (Fig. 10A) and 21.5 m (Fig. 10B). Similar casts have been variously interpreted as root impressions, fish burrows, or bivalve burrows. Large numbers of small, disarticulated fish plates and bones and delicately preserved plant imprints were found at 22 m (Fig. 10B). One of the plants has been identified as the fern, *Archeopteris hallensis* (J. D. Grierson, pers. comm., 1981). A bone and shell lag caps the overlying unit at 26 m. The uppermost unit exposed in the quarry high wall is a complex of thin, rippled sandstones and fissile silty shales with brachiopods throughout. Some flat mud clasts in these sandstones may be rip-ups of desiccation-cracked muds. The brachiopods *Cyrtospirifer* sp. and *Hamburgia* vera were collected from a gray-green shale directly above the coquinite. Bivalves have also been noted, among them *Glossites depressus*, (Bottjer, 1981).

ORIGIN OF THE CARBONATE UNITS: THE REALM OF HYPOTHESIS

Both carbonate units are unique in this part of the Catskill clastic wedge; to our knowledge, units as thick as these have been described from nowhere else in the sequence. Both are well exposed in the quarries where it is possible to observe many features. Both are reasonably well fixed in the stratigraphic sense and their facies context is known to the

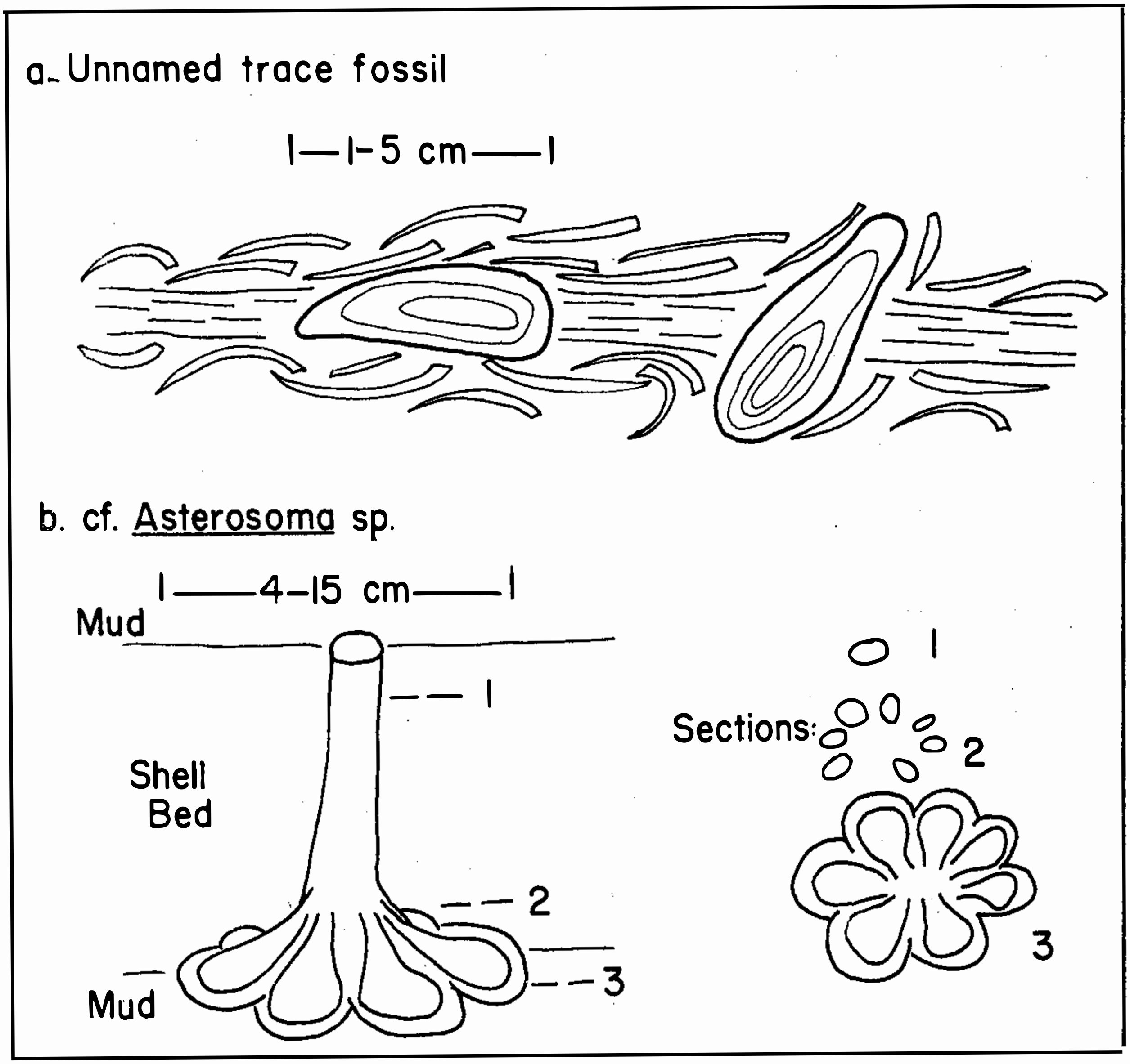


Figure 12. Trace fossils from Case quarry. A. Horizontal burrows with spreiten, shown in vertical section. B. Asterosoma-like feeding burrows. Penetration is 5 to 10 cm. After Bottjer (1981).

reconnaisance level. Salient features of the two units, including those which show similarities and those which set them apart are summarized in Table 2. Even with this information available, a fully satisfying interpretation of the origin of these rocks remains elusive. We offer here working hypotheses in order to stimulate discussion.

Table 2. Comparison of the Carbonate Sequences at Ashcraft and Case Quarries.

A. Features common to both:

Skeletal carbonate content is high in contrast to the enclosing terrigenous clastic rocks.

Bodies are discontinuous or isolated stratigraphically.

Location is toward landward edge of transgressive sequence.

Brachiopod shells dominate with some mollusc and crinoid debris.

Fish-plate fragments and large plant fragments abound.

Shale clasts are common.

Cross-stratification is abundant.

Trough cross-bedding opens westward (seaward).

Current directions are bimodal or polymodal.

B. Contrasting features:

	Ashcraft Quarry	Case Quarry
Geometry	Elongate mound ?	Biostrome, prism, or blanket
	Isolated?	Lateral equivalents
Bedding	Large-scale accretion bedding in inclined wedges	Planar beds enclose cross-bed sets
Color	Light gray, brown mottles	Red
Lithology	Skeletal grainstone (limestone)	Shelly quartz wacke (sandstone)
	Mud-free	Mud common as matrix and clay drapes
	Ankerite nodule clasts	Replacement dolomite
Skeletal alteration	Severely abraded	Generally disarticulated and fragmented but relatively unabraded

Table 2 (continued).

	Ashcraft Quarry	Case Quarry
	Diagenetically altered	Well preserved
Biota	Crinoids rare, bryozoans not observed	Crinoids and bryozoans abundant
Trace fossils	Confined to top surface	Numerous and diverse throughout
	Little bioturbation, especially in shelly beds	Bioturbation common in shelly beds
C. Contrasts in overlying rocks		
Lithology	Sharply bounded sandstone and shale	Intergradational silty shale, siltstone, and sandstone
Bedding	Distinctly layered	Complexly interbedded, lenticular
Color	Medium to dark gray	Gray-green and red
	Fish plates and plant fragments rare	Fish plates and plant fragments locally abundant
Trace fossils	Small, vertical "skolithus" tubes abundant at two levels	A few large ovoid tubes
	Common and varied traces on sandstone soles (hypichnia)	Hypichnia not observed

Ashcraft Quarry

The features of the limestone unit and of the strata surrounding it are explainable in terms of sedimentary process operating in shallow-marine environments where both tidal currents and waves were effective. There are few features of the limestone which suggest subaerial exposure, while the presence of brachiopods and crinoids and the development of a variety of sedimentary structures suggests deposition in shallow marine water. Reversals in current direction indicated by the paleocurrents, the textural maturity of the sand lenses within the limestone, and the lack of mud within the carbonate suggest a shallow-marine setting in which strong tidal currents winnowed out the fines and abraded the shell materials.

Shells, quartz sand, shale clasts, reworked nodules, plant fragments, and bones were all transported to this locality. The nodules and shale clasts must have been transported by strong currents from sources not too far distant, judging from the large clast size and relative lack of abrasion. The shells must have been transported from the nearby sea floor with extensive concentration and reworking to account for their numbers and abraded condition.

The internal plan of the carbonate mass seems to require three kinds of sedimentary processes: a) erosion and transport of sand, shells, nodules, etc. to the site; b) vertical accretion to form positive depositional relief; and, c) lateral accretion to produce the ultimate accumulation as either an isolated mound or a tabular body.

Thus, the carbonate mass appears to have been an accumulation built up above its surroundings by currents bringing to the site materials from the nearby sea floor or lagoon and from nearby terrestrial sources. Five hypotheses of accumulation have been suggested, no one of which is completely satisfactory or can be tested adequately with the available data. They are offered here as a basis for discussion.

Deposition as a subaqueous "shell mound" seaward of a beach/lagoon complex and/or a tidal flat was suggested by Krajewski and Cuffey (1976). Bowen (1978) postulated a "break-point bar" offshore from tidal flats. Both Krajewski and Cuffey (1976) and Bowen (1978) suggested significant contributions of skeletons produced *in situ* once initial relief above the sea floor was established. Another possibility is deposition on the subaqueous part of a land-tied accretion lobe or spit (Enos and Minero). Accumulation in the form of a tidal delta with both ebb and flood deposits represented has been suggested by John Bridge (pers. comm., 1981). Finally, some of the features in the unit are compatible with development as a small, mostly submerged, barrier bar as hypothesized by Woodrow.

In any event, nodules and other clastics were brought to the site of accumulation as the result of fluvial or shore-zone erosion and transport. A swamp seems the most likely source of ankerite nodules and abundant plant material. Shale clasts could have come from either the landward side or the seaward side of the carbonate accumulation. The source must have been one where mud normally accumulated and was periodically eroded. Wave and/or tidal scour of the nearby shelf provided the shells. Tides and waves reworked these particles into the limestone we see now.

Case Quarry

The points of similarity between the two carbonate bodies (Table 2) are such that we conclude that both were formed in tide-influenced marine environments. However, contrasts between them are sufficient to make it clear that the local geography of the Catskill shoreline at the two sites must have been different. The abundance of brachiopods and the presence of crinoids and *in situ* bryozoa demonstrate that the environment of deposition of the coquinite was subtidal marine. Tidal effects are indicated by material from both marine sources (shells) and terrestrial sources (plant fragments, red muds), by the intimate intermixture of sandstone and shale (including flaser bedding), and by some examples of reversals in current direction. Most of the large-scale cross-strata record flow toward the west or northwest suggesting ebb-dominated deposition.

If the question of process is tentatively answered, we are left with the question posed by the mixture of materials in the coquinite. The source of the shell material was the local sea floor, despite the apparent ebb dominance, but the source of the red mud is less obvious. A source of highly oxygenated muds is required, perhaps from the higher, subaerial parts of a tidal flat or nearby alluvial plains. Plant debris could derive from the same sources. Shells in great quantity require a large community of epifauna either close to or as part of a tidal shore. The bryozoan clusters, at least, point to some production in situ.

The coquinites of the Case quarry have been interpreted as a part of a tidal delta (Woodrow) and as a subtidal zone of a tide-dominated fluvial delta (Bottjer). Strata above the coquinite indicate alternations of shallow marine and non-marine or supratidal environments. They contain mudcracks, in situ pedogenic carbonate nodules in red mudstones, and the enigmatic burrows or root cases; interlayered are beds containing marine fossils.

The local Upper Devonian shoreline was dominated by tidal processes, not by large streams and fluvial-dominated deltas. Material delivered to the shore appear to have been carried by small streams draining an alluvial plain or in channels of a tidal coast. Evidence of a large tidal range is lacking; a range of less than a couple of meters would probably account for the tidal features. Flow velocities were high enough in some areas, however, to move coarse material (shells and sand) as well as fines and to deposit them as migrating dunes and ripples. The localization of thick carbonate units may result from local amplifications in the tidal range or tidal velocity perhaps caused by indentations in the shoreline (bays).

In summary, both sequences appear to result from the concentration of shell debris, quartz, rock fragments, nodules, and wood by high-energy sedimentary processes in ebb-dominated tidal environments. Differences in lithology and geometry between the two units probably reflect local differences in the shoreline.

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ROAD LOG FOR BIOCLASTIC CARBONATE UNITS IN THE CATSKILL CLASTIC WEDGE

CUMULATIVE MILEAGE	MILES FROM LAST POINT	ROUTE DESCRIPTION
0.0	0.0	Begin trip at main entrance to SUNY Binghamton (Harpur College) campus, jct. of Glenn G. Bartle Drive with N.Y. 434. Go west (left) on N.Y. 434, but hold right to exit on N.Y. 201.
0.15	0.15	Exit right (N) onto N.Y. 201 toward Johnson City.
0.7	0.55	Bridge over Susquehanna River.
1.0	0.3	Enter Johnson City traffic circle (with caution!); prepare to exit right on Riverside Drive west (3rd exit).
1.1	0.1	Exit right (NNW) into Riverside Drive (N.Y. 201). Follow signs to N.Y. 17 west.
2.0	0.9	Exit right onto cloverleaf entrance to N.Y. 17 west.
4.6	2.6	Susquehanna River.
10.8	6.2	Apalachin, N. Y.,exit. Continue west on N.Y. 17.
14.0	3.2	Esker on north (right) side of N.Y. 17. Much of esker and associated kamic deposits have been removed for aggregate.
19.7	5.7	Rest area, westbound lane.
20.3	0.6	Steep wooded hill with small exposures of Chemung (shallow marine) facies.
30.7	10.4	Road cut, Chemung facies.
32.7	2.0	Susquehanna River.
36.9	4.2	Exit right for U.S. 220. Turn left (S) on U.S. 220 at stop sign.
40.1	3.2	Chemung River.
40.9	0.8	Exposure of Chemung facies on right (W).
41.8	0.9	Jct. Pa. 199; continue south on U.S. 220.
47.0	5.2	Road cut in Wiscoy Fm. (?), Chemung facies, (shallow marine).

48.0	1.0	Blinker light at Bridge St., Ulster, Pa.
51.3	3.3	Road cut in lower Towanda Fm. Cattaraugus facies; red beds, some coquinite.
52.6	1.3	Turn right (W) on U.S. 6.
53.6	1.0	Road cut in Towanda Fm. with abundant flow rolls (pillow structures).
57.6	4.0	Community of Luthers Mills.
59.3	1.7	Enter Louis Case quarry on right (N) side of U.S. 6. Obtain permission from Louis Case in houst at west edge of quarry. STOP 1.

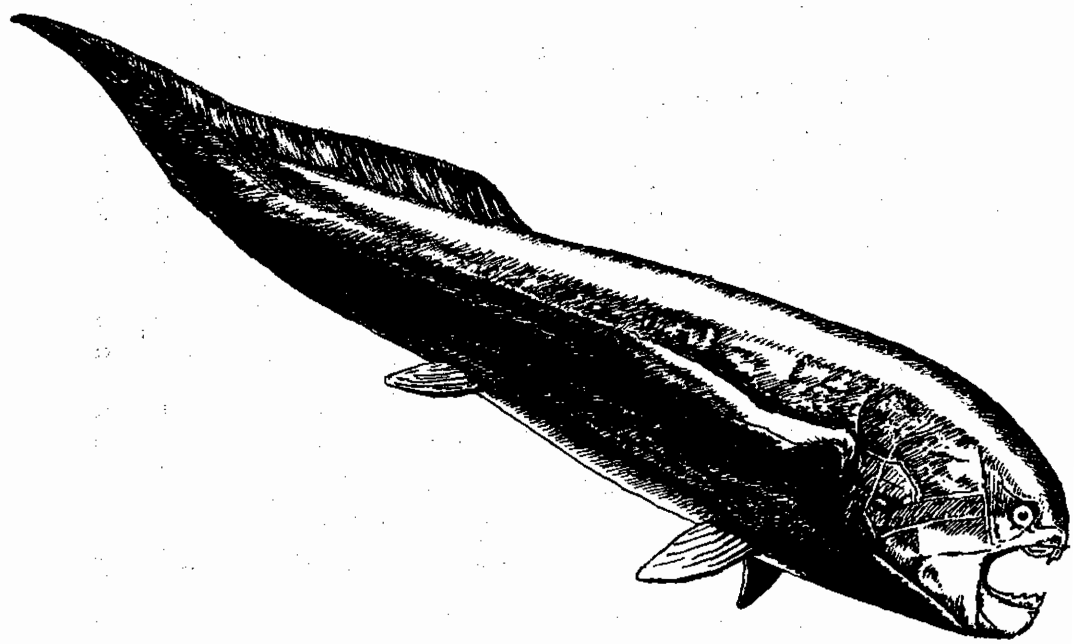
STOP 1. LOUIS CASE QUARRY, Burlington, Pa. Start in small face below main bench of quarry. Work upward toward east end of quarry.

59.4	0.1	Enter U.S. 6 eastbound by turning left at quarry entrance. Retrace route to Apalachin, N. Y.
59.6	0.2	Kiln on left (N) side of road where coquinite was exploited for agricultural lime and mortar. This is the type locality of the Luthers Mills Coquinite.
63.6	4.0	Jct. township road. Large blocks of coquinite exposed in bed of Sugar Creek at sharp curve to west approximately 1/2 mi. north of U.S. 6. Long road cut in Towanda Fm. beginning at curve on township road.
65.5	1.9	Overview of Susquehanna Valley to north (left).
66.1	0.6	Turn left (N) on U.S. 220.
66.8	0.7	Overview up Susquehanna Valley to north.
67.4	0.6	Road cut in Towanda Fm.
71.7	4.3	Road cut in Wiscoy Fm. (?)
75.0	3.3	Milan, Pa. Continue north on U.S. 220.
81.8	6.8	Turn right (E) onto N.Y. 17.
89.4	7.6	Rest area at Tioga Park race track (a monument to human folly). Potential lunch stop.

100.8	11.4	Owego, N. Y. Continue east on U.S. 17.
108.1	7.3	Exit to right for Apalachin (Exit 66). Turn left (E) immediately on N.Y. 434 at stop sign.
110.2	2.1	Broome-Tioga County line.
110.6	0.4	Turn right (S) into Tracy Creek Road. Follow it through community of Ross Corners.
111.3	0.7	Outcrops of Rhinestreet Fm., Chemung facies, to right in bed of Tracy Creek.
115.4	4.1	Jct. with O'Connell Rd. Tracy Creek Rd. becomes Collins Rd. Continue ahead and bear right up hill.
116.3	0.9	Pa.-N.Y. state line.
116.35	0.05	Turn right on unmarked road at locked gate. Entrance to Ashcraft quarry. Permission to visit quarry is obtained from Ashcraft Excavating Co. on Pennsylvania Ave., 2.5 mi south of N.Y. 434 in Apalachin, N. Y.
117.3	0.95	Follow road into Ashcraft Quarry. STOP 2.

STOP 2. ASHCRAFT QUARRY, Little Meadows, Pa. Start in pit near east end of quarry. Work along main face to west end. Climb onto bench at west end.

118.25	0.95	Return to Collins Rd. at gate. Turn left (W) and follow Collins Rd.-Tracy Creek Rd. back to N. Y. 434.
124.0	5.75	Tracy Creek Rd. ends at N.Y. 434. Turn right (E) on N.Y. 434 and continue through Vestal.
131.3	7.3	Main entrance to SUNY Campus, Bartle Drive. END TRIP.



Dinichthys, the largest Devonian placoderm.
From B. Kummel, 1970, History of the Earth,
p. 238. Redrawn by Kevin Enos.

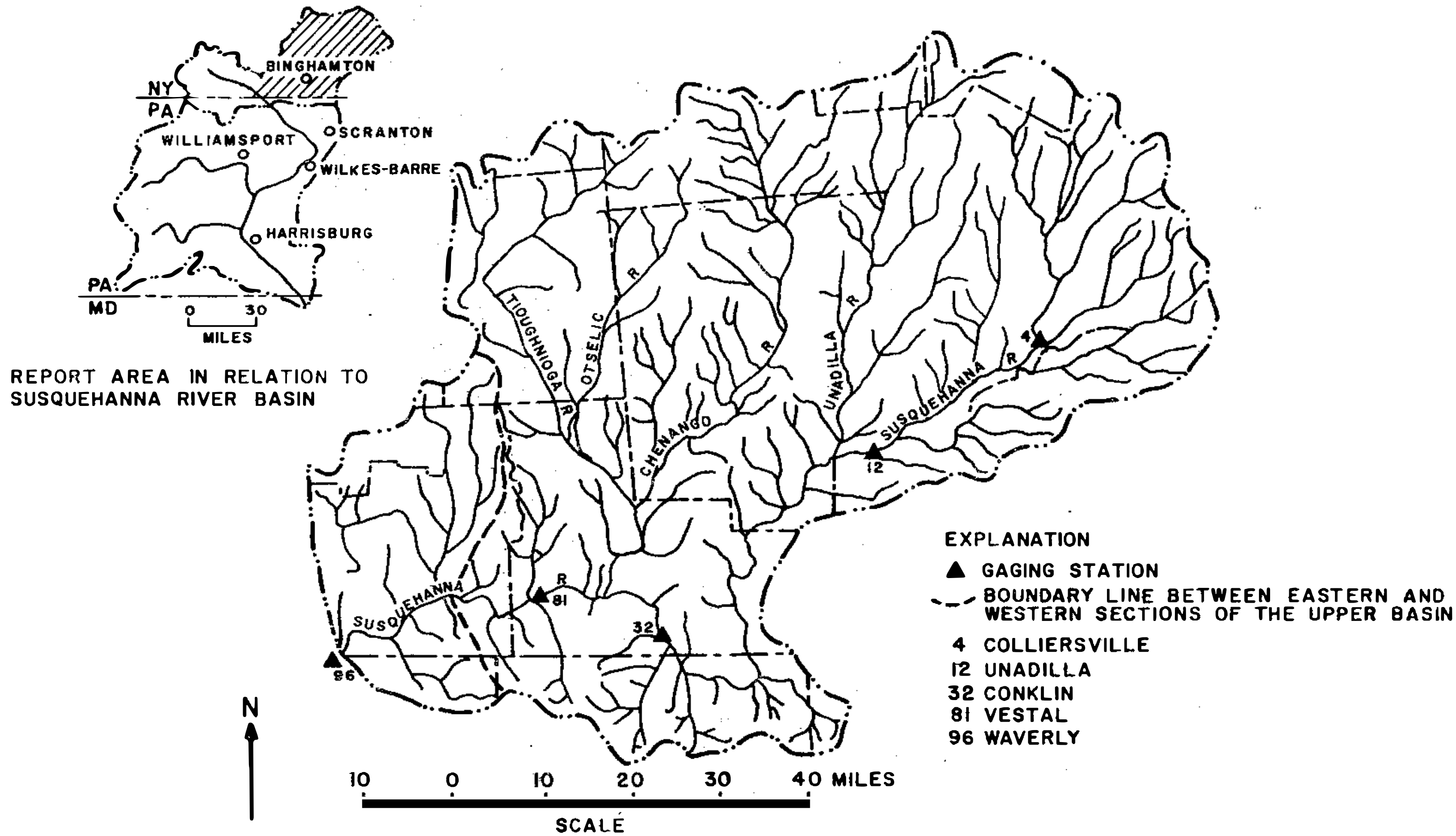


Figure 1. Index map of the eastern Susquehanna River basin.