A SUCCESSION OF DEPOSITIONAL ENVIRONMENTS IN THE MID-ORDOVICIAN SECTION AT CROWN POINT, NEW YORK

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Introduction

The Crown Point section, exposed at the Crown Point State Historic Site, is a wonderful place for using fossils, sedimentary textures and structures, and lithologies to interpret changing environments of deposition. Formations exposed in the 120 meter (400 feet) thick section include the Crown Point, Valcour, Orwell, and Glens Falls limestones, deposited between about 458–444 million years ago on the eastern margin of North America. The rocks record the onset of the continent-arc collision known as the Taconic Orogeny. The lower half of the section records deposition on a slowly subsiding, passive continental margin. The upper half records a swift transition to deeper water environments as the continental margin entered the subduction zone. At Crown Point these rocks comprise a homoclinal section dipping about 8 degrees to the west-northwest.

The Middlebury College geology department uses the Crown Point section as a field exercise for both first- and second-year geology students. Their field trip as well as yours consists of a walking tour beginning about 500 meters southeast of Fort Crown Point, heading towards and through the Fort, and then continuing west for about 200 meters along the Lake Champlain shoreline. We will visit most of the lettered stations shown on the index and air photo maps (Figs. 1 and 2). The lettered stations are also shown on the detailed columnar section (Fig. 3) and the student columnar section (Fig. 4). For historical purposes Figure 3 also shows Raymond's (1902) sections B and C; he listed a large number of fossils from those sections. Appendix A (reprinted from Baldwin and Mehrtens, 1985) diagrams the fossils occurring in this section.

Absolutely no collecting or rock hammers are allowed in the Crown Point State Historic Site. Its pristine condition is maintained because the many geologists who have visited over the years have honored this rule. It is useful to circle fossils with chalk for the aid of others.

[1] Brewster Baldwin passed away on July 12, 1992.

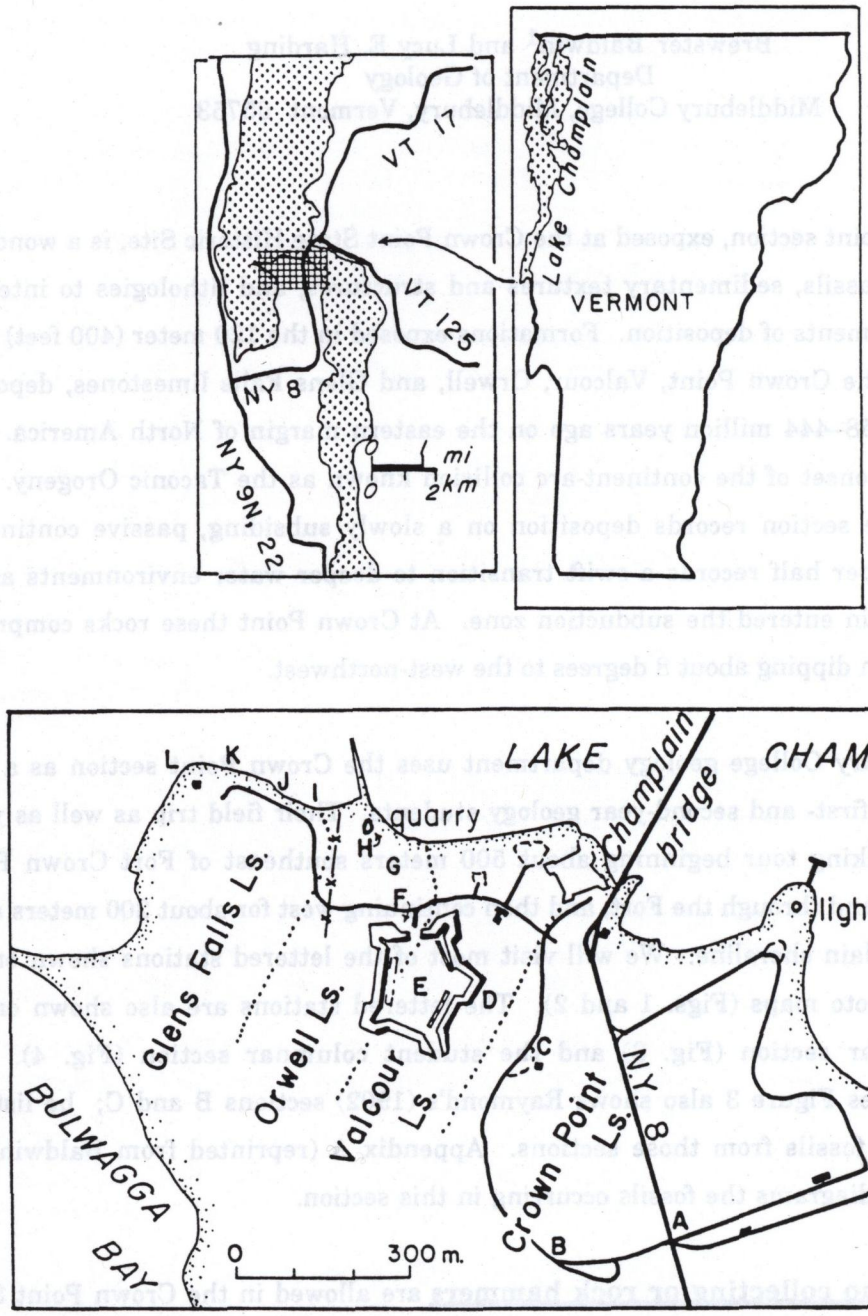

Figure 1. Maps showing location of the Crown Point Historic Site along the western shore of Lake Champlain. Detailed map shows roads, landmarks, and Stations A–L that are described in this field guide. Contacts between the Crown Point, Valcour, Orwell, and Glens Falls limestones are also shown. Compare with Figure 2. Maps after Baldwin (1980); reprinted with permission from *Northeastern Geology*.

Figure 2. (Opposite page) Aerial photograph of Crown Point showing field stations and historic ruins. Scale approximately 1:7,500.


LAKE CHAMPLAIN
Fort St. Frederic
French 1734
Pier
lighthouse
N
0
500
1000
feet
light infantry redoubt
gate
A
B
C
D
E
F
G
H
I
pavilion
park
visitor center
Fort Crown Point
English 1759
quarry
private
CROWN POINT
N.Y.
Bulwaga
Bay

D3

For a more detailed tectonic analysis and petrographic descriptions of this section consult Baldwin (1980, 1982, 1987), and Baldwin and Mehrtens (1985). You may want to follow along with Figures 2 and 4 and Appendix A during the field trip. These figures and the appendix, along with some general instructions, are given to our students at the beginning of their Crown Point adventure! Students are asked to measure a strike and dip at A and then to calculate the thickness of the covered interval from A to B and from A to D using the air photo (Fig. 2). They also sketch a columnar section at A and describe the rocks at A and B. For Stations D and above they use Figure 4 as a guide.

The Crown Point limestone — Stations A, B, and C

A six-meter interval of the Crown Point limestone, belonging to the Chazy group, is exposed at Station A (Figs. 2 and 3). Uneven dolomite laminae (brown- or cream-weathering) are interlayered with lime-mud (gray-weathering) containing abundant rounded grains of calcite and fossil fragments. Bedding is horizontal and locally extensively burrowed. Fossils include abundant *Girvanella* (algae), nautiloids, *Maclurites* (gastropods), along with trilobite fragments and several brachiopods. These strata are interpreted to have formed in a low-energy tidal to subtidal environment. The dolomitic laminae may represent algal mats of the supratidal zone.

Much of the interval between Stations A and B is covered (Fig. 3). The two meter thick exposure of Crown Point limestone at Station B consists of bidirectionally cross-bedded lime-sand with rare grains of quartz. These characteristics suggest oscillating currents and a higher energy environment than at Station A, possibly a beach zone or the lower sand flat region of the tidal zone.

The limestone and dolostone beds near the picnic pavilion make up Station C. These beds, along with strata beneath the rampart between here and Station D, have not been studied but contain *Maclurites* and some trilobite fragments.

The Valcour limestone — Stations D and E

Station D is just outside the easternmost corner of the British fort, up a concrete sidewalk from the Crown Point Visitor Center. Here the Valcour limestone, which forms the upper part of the Chazy group, consists of laminated to thinly-bedded limestones and dolostones cut by channels and scour surfaces. Many strata show low-angle, bidirectional cross-bedding. The exposed face at Station D is about 3 meters high and the outcrop continues in the moat along strike to the south-southwest for about 100 meters to the southern

entrance to the fort (Figs. 1 and 2). Several scour surfaces can be followed for some distance along the moat to the south. The lower beds at Station D consist of limestone with fossil fragments and dolomitized burrows. Interbedded limestone and dolostone (dolomite rhombs are visible with a hand lens) form the upper beds at Station D. Near the top of the face are dolostone beds with floating limestone clasts. In thin section the dolostone layers contain pellets. Did the dolomite only replace layers which originally had the greatest porosity? Fossils include *Maclurites* and mounds of gastropod shells. The lack of fossil diversity, cross-bedding, scour surfaces, channels, and dolostone suggest a tidal environment of deposition.

Inside the fort, the flat exposures in front of the southernmost barrack make up Station E (Figs. 1 and 2). The rock is similar to exposures at B, a bidirectionally cross-bedded lime-sand with scattered quartz grains. There are small plano-spiral gastropods and limestone clasts in some of the highest beds. As at B, the sand-sized grains, bimodally oriented cross-beds, and lack of faunal diversity suggest a relatively higher energy environment, possibly a beach, shoal, or lower sand flat in the tidal zone. Above E to the northwest is a low ledge of brown dolostone and next is a 0.6 meter thick ledge of medium- to coarse-grained, almost pebbly quartzite. A three meter thick covered interval separates the Valcour from the overlying Orwell limestone, exposed just outside the northern entrance to the fort. The dolostone and pebbly quartzite suggest that a shallow water, high-energy environment continues through Station E.

The Orwell limestone — Stations F, G, H, and I

The Orwell limestone differs from the Crown Point and Valcour limestones in that it is a thick-bedded, massive, light-gray limestone with areas of secondary black chert (present both as nodules and entire beds). The limestone is predominantly a lime-mud with only a few beds of lime-mud clasts and rare evidence of cross-bedding. Dolostone layers or quartzite are not present in the Orwell, although some burrows have been dolomitized. The massive bedding suggests extensive burrowing. Fossils are diverse and plentiful.

The Lowville beds form the lowermost part of the Orwell limestone (Fig. 3). They are exposed at Station F in a 5 meter high face, just outside the northern fort entrance, and also in the building stone in the southern barrack. This interval consists of very light gray-weathering, massive lime-mud and contains the vertical tubes of the trace fossil *Phytopsis*. The fine grain size suggests a very low-energy environment, possibly a lagoon adjacent to the Valcour tidal zone. Near the top of the face are more typical gray limestones

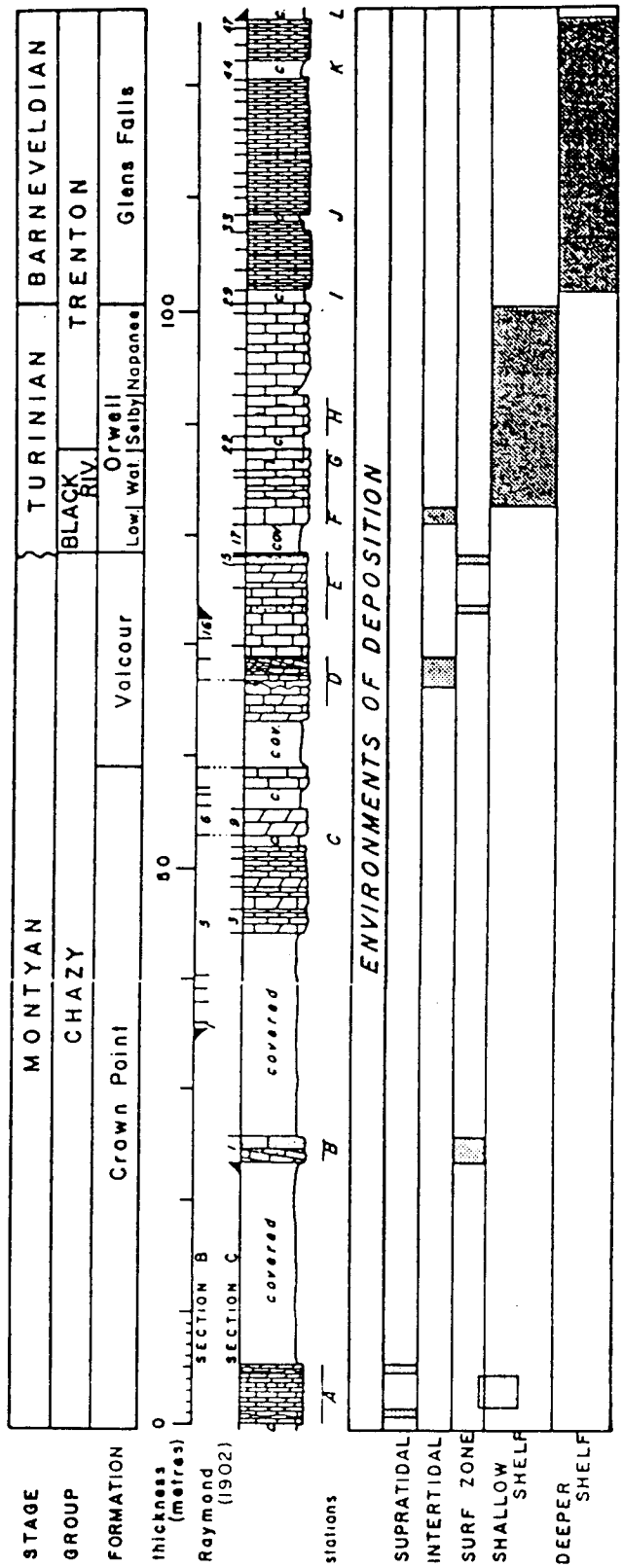

Figure 3. Columnar section for Crown Point. Station letters A–L correspond to the localities shown in Figures 1 and 2. Stratigraphic terminology is from Fisher (1977). The Orwell is divided into the Lowville (Low.), Watertown (Wat.), Selby, and Napanee units. Column from Baldwin (1980); reprinted with permission from *Northeastern Geology*.

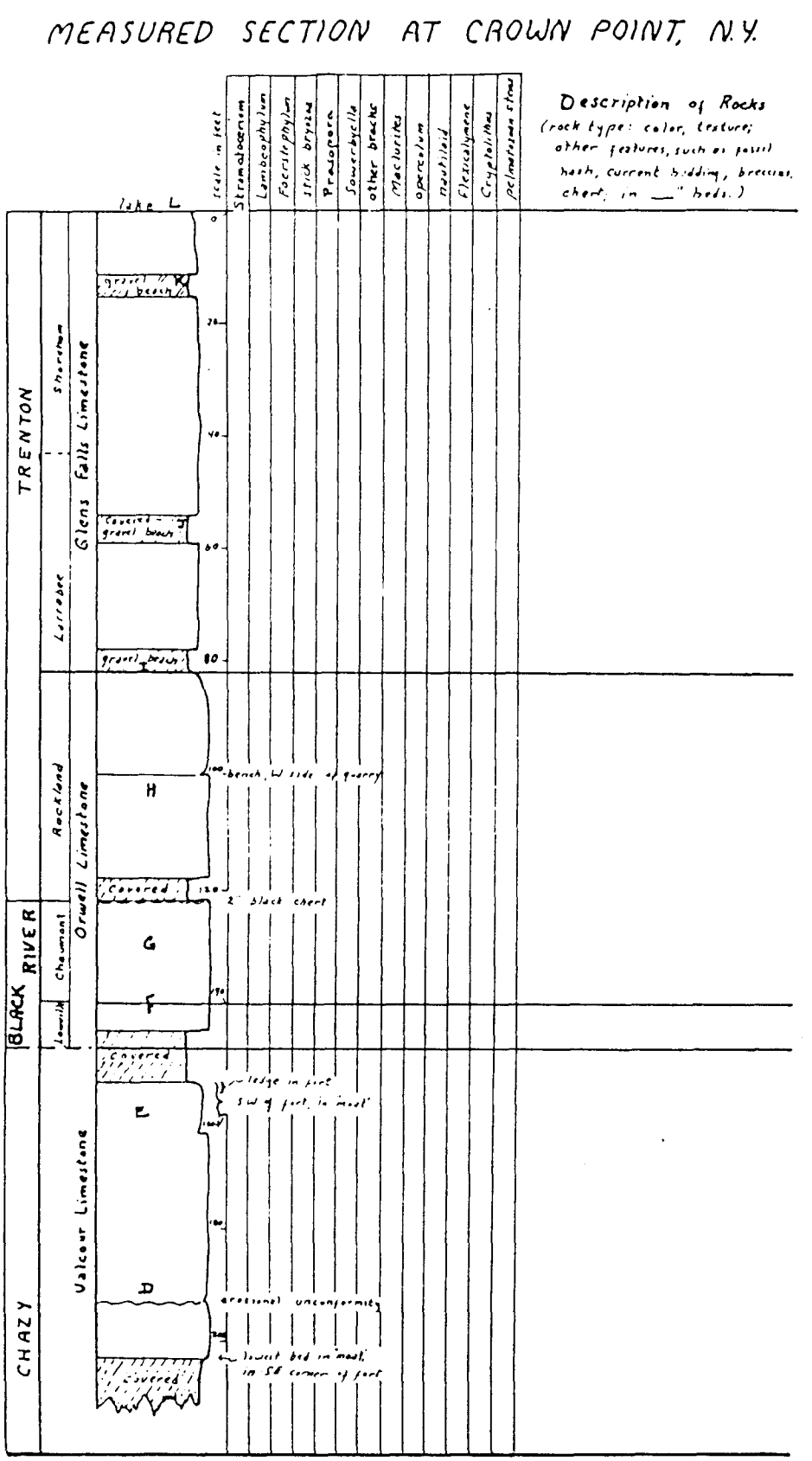

Figure 4. Measured section at Crown Point, N.Y., student's copy. Letters refer to stations on Figures 1 and 2.

of the Orwell and a layer containing black chert nodules. Above the Lowville begins the section of abundant fossils.

Walk north across the road and onto an extensive Orwell ledge towards Station G and Lake Champlain. Along the way, on various levels of the ledge, are exposed clusters of the solitary coral *Lambeophyllum*, nautiloids, the stromatoporoid *Stromatocerium*, gastropods including *Maclurites* , *Lophospira*, and the high-spired *Hormotoma*, the colonial coral *Foerstephyllum* , the trilobite *Isotelus*, brachiopods, some stick bryozoan fragments and a few pelmatozoan stems. Appendix A will help in identification. At the lake shore is a 2 cm thick black chert bed containing beautifully replaced costate brachiopods. This chert bed marks the top of the Black River group (Fig. 3). Note the glacial striations in the shoreline rocks.

Station H is an old quarry located along the lake shore, just west of the chert bed. Large quarry blocks contain many stick bryozoans, the "derby hat" *Prasopora*, pelmatozoan stems, brachiopods, and an occasional *Isotelus*. Just above the western quarry wall is a ledge containing cross-bedded limestone. Walk north from the quarry back to the lake shore just south of the spit. Note the opercula (lids) of *Maclurites* along with *Lambeophyllum*, *Foerstephyllum*, *Stromatocerium*, and the clam *Ambonychia* in the upper beds of the Orwell limestone.

The fine grain size and rare cross-bedding in the Orwell suggest a low-energy depositional environment. The corals and grazing snails suggest deposition within the photic zone under conditions of normal salinity. The depositional environment was probably shallow but subtidal, possibly in a sheltered bay or lagoon with good circulation.

The Glens Falls limestone —Stations I, J, K, and L

Station I is the gravel beach covering the contact between the Orwell limestone and the overlying Glens Falls limestone. Stations J and K are also gravel beaches and K and L are on private property. **Please do not go onto this private property.** After examining the Glens Falls limestone return to the visitor center by walking east along the shoreline or on the road that is just inland.

The gray Glens Falls limestone is immediately distinguishable from the Orwell by its thin-bedded, flaggy outcrop habit. Beds are 5 to 10 cm thick and many are graded or consist of two parts. The lower part contains coarse-grained fossil fragments; the upper part is

lime-mud. Near Station K are some thin shaley laminae above the lime-mud. This shale is interpreted to be the precursor of the Trenton shale which overlies the Glens Falls in northern Vermont and Québec. Fossils include diverse brachiopods *(Rafinesquina, Dinorthis, Dalmanella, Sowerbyella),* fragments of trilobites *(Flexicalymene and Cryptolithus),* stick bryozoans *(Eridotrypa and Stictopora), Prasopora,* and pelmatozoan stems. *Stromatocerium, Maclurites,* and the corals are absent.

The graded beds and the absence of corals and snails suggest deposition below wave base and the photic zone. The environment of deposition is interpreted to be deep water on an open continental shelf.

Depositional environments and tectonic interpretation

The following discussion comes largely from Baldwin (1987). Fossils, sedimentary textures and structures, and lithologies are used here to reconstruct three sequential depositional environments for the Crown Point section. The Crown Point and Valcour limestones (along with the older Cambrian and Ordovician sediments of west-central Vermont) appear to have been deposited at about sea level on the passive margin of proto-North America (Fig. 5). The Orwell was deposited in slightly deeper water but still within the photic zone, possibly in a quiet lagoon or bay. The Glens Falls limestone was deposited in still deeper water, below the photic zone and wave base on an open continental shelf. Thus the Crown Point section records a deepening of the ocean with time. To the north this deepening of the ocean was recorded by deposition of 1.5 km of marine shale of Trenton age, indicating more rapid subsidence of the shelf. This episode of subsidence reflected in the Crown Point section and the Trenton shale, in which the ocean deepened more rapidly than sediments could accumulate, marks the onset of the Taconic Orogeny.

Figure 5 uses the regional stratigraphy of Cady (1945) to illustrate the subsidence history. The time scale is from Harland and others (1964) and Churkin and others (1977). The thickness at the time of deposition (T_d) of the proto-American platform section and overlying deeper water shale was calculated from the present thickness of strata in west-central Vermont (Baldwin, 1980). This was done by decompacting the present thickness using compaction data of Baldwin and Butler (1985).

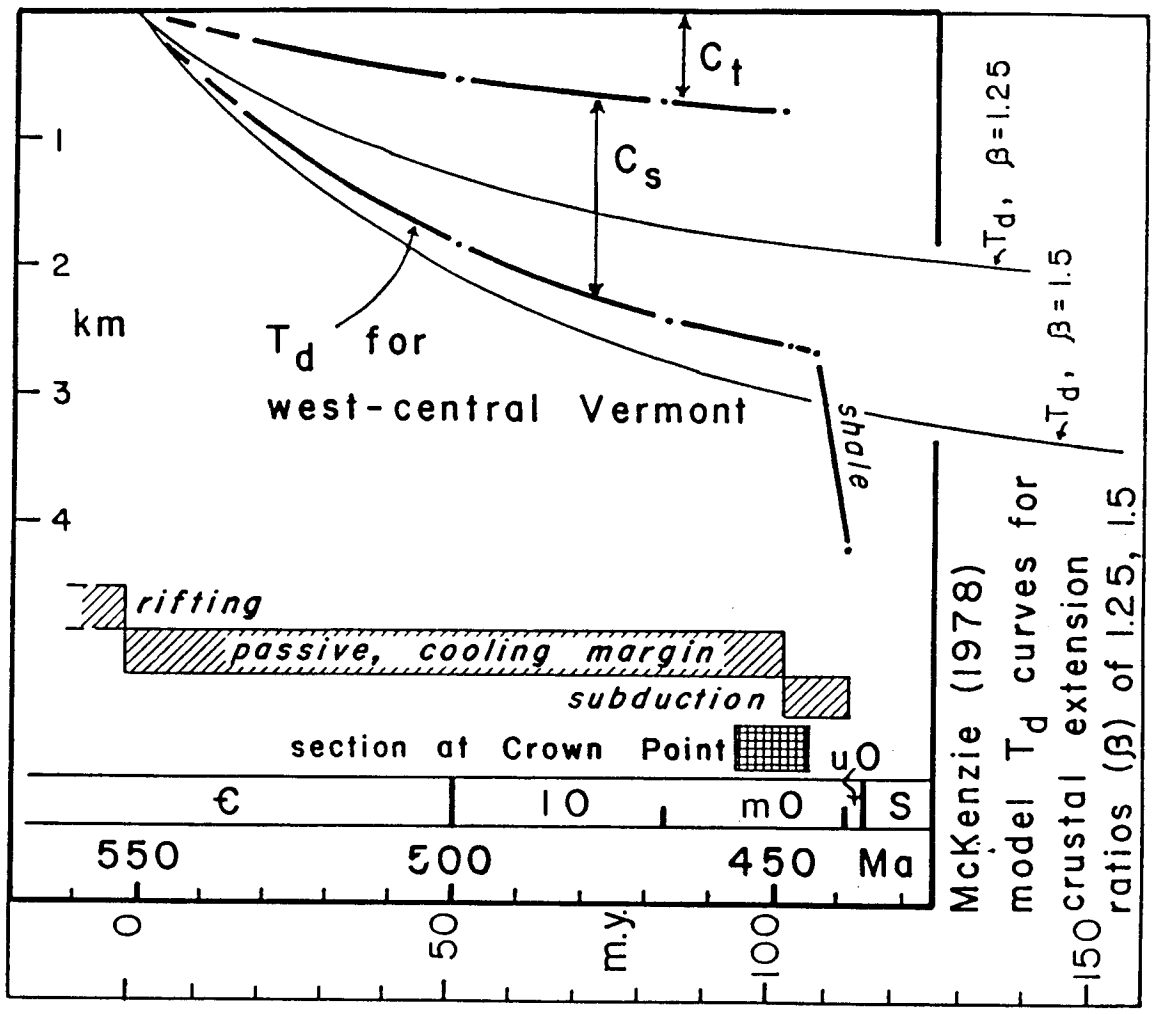

Figure 5. Cumulative thickness (T_d) of the west-central Vermont section, compared with model curves of McKenzie (1978): T_d = deposited thickness; C_s = crustal subsidence due to sedimentary loading; C_t= crustal subsidence due to tectonism; ß = crustal extension ratio. From Baldwin (1987).

Following principles of McKenzie (1978), space for T_d was provided by crustal subsidence due to tectonism (C_t) plus crustal subsidence due to loading (C_s). The magnitude of tectonic subsidence (C_t) depends on how much the continental crust was stretched and thinned during rifting. The rate of C_t was determined by thermal cooling.

One value each of T_d and C_s was calculated for the end of the Cambrian and for the Early Ordovician. An additional value of T_d and C_s was calculated within Mid-Ordovician time, corresponding roughly to the time of deposition of the Chazy Group (Crown Point and Valcour limestones). Values of T_d were also calculated for sediments accumulating later in Mid-Ordovician time corresponding to the end of deposition of the Glens Falls limestone and end of deposition of the Trenton shale. To do this, average

densities were calculated for the accumulating section using density values and burial depths from Baldwin and Butler (1985). The sediment density averaged 2.3 g/cm^3. This value, compared with an assumed mantle density of 3.3 g/cm^3, indicates that C_s accounted for 70% of the total subsidence, and the remaining 30% was due to C_t.

The tectonic control of T_d is shown in Figure 5 which compares the west-central Vermont section with model curves of McKenzie (1978) for sediment thickness T_d. The McKenzie curves reflect thermal cooling accompanying crustal extension ratio (ß) of 1.25 and 1.5. The T_d curve for west-central Vermont suggests ß of about 1.4.

Thus, the Cambro-Ordovician section of the ancient continental platform, up through deposition of the Chazy group, fits McKenzie's data for a rifted and then thermally cooled, passive continental margin. Incidentally, Figure 5 also indicates that rifting ended about 550 Ma; this is in general agreement with more elaborate studies of Bond and others (1984). Strata younger than the Chazy group were deposited on a rapidly subsiding continental margin that was being forced to enter the subduction zone at the onset of the Taconic Orogeny.

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APPENDIX A

Fossils of the Crown Point, New York, section. From Baldwin and Mehrtens (1985); reprinted with permission from the Vermont Geological Society.

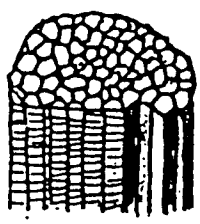
Algae
Girvanella (x 1) "cocktail-onion"; concentric layering, small, abundant.

Stromatoporoid
Stromatocerium rugosum (x 1/10)
irregular, sub-concentric masses to 30 cm across (looks as though a cow just went by)

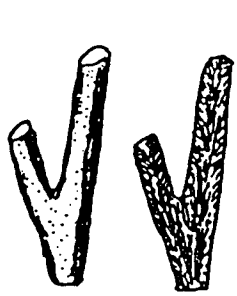
Corals (Coelenterates)
Lambeophyllum profundum (x 1)
oldest genus of solitary coral in geologic record; shaped like ice-cream cone; presumably lived in shallow photic zone with algae.

top side

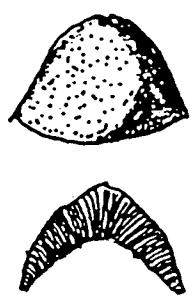
Foerstephyllum wissleri (x 1)
honeycomb variety of colonial coral; presumably lived in shallow photic zone with algae; this species named after Professor Benjamin Wissler, Middlebury College. Sketch shows top (honeycomb) and side (columns; cut-away columns with interior tabulae).



Bryozoans (x 2, x 1)
Colonial coral-like animals with microscopic tubes for each individual; surface has tiny pin-hole apertures, visible with hand lens; interior has hair-like fibers. Bryozoans are filter feeders, needing clear water.



(shape and cross-section) "stick"



Prasopora

Brachipods (2 shells) (x 1, 1/2)
Varieties are wide or narrow-hinged, smooth or marked with radiating lines or ribs; some show concentric growth lines. Diverse assemblage of brachiopods indicates open marine conditions.

a. Sowerbyella; b. orthid; c. rhynchonellid

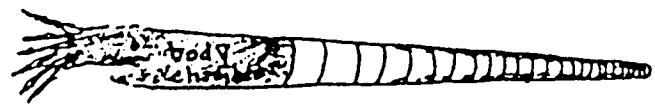
a.

b.

c.

APPENDIX A (Continued)

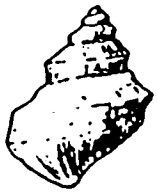
Nautiloids (x 1/5, 1/10)
Belong to Mollusca, Cephalopoda. Related to squids; swimmers, predators. Chambers behind body chamber are preserved.



Gastropods (Mollusca; snails)
Maclurites is flat-coiled; probably grazed on algae in very shallow water. Its operculum is a thick-walled "hand"-shaped lid. Many snails have moderate to high spires (coils).

x 1/5
Maclurites

x 1/3
opercula

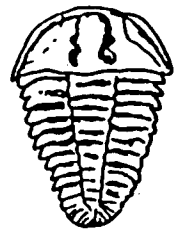


x 1
Lophospira

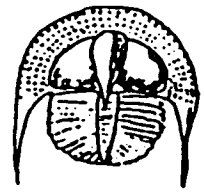
x 1
Hormotoma

x 1/2
Lecanospira

Trilobites (x 1)
Belong to Arthropoda. Like locusts, they molted, so one animal could leave many exoskeleton fragments. The cephalon (head region) is most important part for identification.



Flexicalymene



Cryptolithus

Pelmatozoans (x 1/2)
Belong to Echinodermata. Pelmatozoan stem (of crinoid, cystoid, etc.) comes apart in the sediment, leaving disks with round or star-shaped holes; cup with the living chamber seldom found here. Echinoderms live only in water of normal salinity.