Merguerian, Charles; and Sanders, J. E., 1996a, Diversion of the Bronx River in New York City - evidence for postglacial surface faulting?, p. 131-145 *in* Hanson, G. N., *chm*., Geology of Long Island and metropolitan New York, 20 April 1996, State University of New York at Stony Brook, NY, Long Island Geologists Program with Abstracts, 177 p.

DIVERSION OF THE BRONX RIVER IN NEW YORK CITY - EVIDENCE FOR POSTGLACIAL SURFACE FAULTING?

Charles Merguerian and John E. Sanders
Geology Department, 114 Hofstra University
Hempstead, New York 11550

INTRODUCTION

North of the New York Botanical Garden, near the Mosholu Parkway in the Bronx, the NW-SE-trending Mosholu Parkway fault offsets the Bronx River valley (a NNE-SSW-trending strike-valley lowland underlain by the Inwood Marble) from the Webster Avenue lowland (another NNE-SSW valley also underlain by the Inwood Marble). The Amtrak-Metro North railway follows these two lowlands. Just at the point of offset of the marble lowland, the Bronx River leaves its former wide NNE-SSW-trending strike-valley lowland and occupies a narrow N-S-trending gorge, here named the Snuff Mill gorge, cut across the more-resistant Hartland Formation (the "gneiss" of Kemp, 1897 and "Manhattan Schist" of Schuberth 1968 and many others). In Kemp's words:

"The Bronx, however, at a point, a half a mile or so below Williams Bridge, and just above Bedford Park Station, and in the upper portion of the area assigned to the Botanical Garden, abruptly leaves its old valley and breaks across the enclosing ridge of gneiss, in a gorge 75 feet deep. For nearly a mile it occupies this gorge and then reaching more open (sic) country, with a rocky fall at Bronxdale and another at West Farms, it makes its way to the sound.

The geologic literature contains two concepts about the origin of the Snuff Mill gorge, which is a first-order drainage anomaly. According to Schuberth (1968, p. 88), the Bronx River formerly followed the marble lowland, but about 20 million years to 30 million years ago, was diverted into its N-S-trending course following a N-S-trending fault along which the Schuberth contends the schist has been deeply decomposed.

By contrast, Kemp (1897) proposed four hypotheses of diversion, all but one of them connected with Pleistocene glaciation. Although he preferred the concept of ice blockage of the Webster Avenue lowland as the mechanism for causing the Bronx River to cut the Snuff Mill gorge, Kemp admitted that the duration of the ice-blocking episode is embarrasingly short in comparison to the time required to erode the gorge. Kemp mentioned an outcrop of gneiss just E of the RR culvert over what he took to be an abandoned channel and suggested that here the river had "surmounted" a bedrock "reef."

In this paper, we present new evidence about the tectonic features in the bedrock, based on Merguerian's field observations, and subsurface information in the two valleys that we have obtained from the archives of the City of New York. We conclude that the new tectonic data refute Schuberth's concept that the Snuff Mill gorge coincides with a weak zone in the schist along a N-S-trending fault. Our data further substantiate Kemp's assignment of a post-glacial age to the Snuff Mill gorge. We think the Bronx River did not "surmount" a bedrock "reef," but rather was blocked by postglacial elevation of a bedrock barrier formed adjacent to the NW-trending Mosholu Parkway fault (of Baskerville, 1992). Significantly, we offer the first evidence for induced surface changes in response to neotectonics in the New York City area.

REGIONAL GEOLOGY

New York City (NYC) is situated at the southern terminus of the Manhattan Prong (Figure 1), a deeply eroded sequence of northeast-trending metamorphosed Proterozoic to Lower Paleozoic rocks. The sequence extends and widens northeastward to form the crystalline terranes of western Connecticut and Massachusetts and extends, in significantly lower metamorphic grade, northward as the Taconic sequence in eastern New York. South of NYC, the crystalline rocks of the Manhattan Prong plunge beneath Mesozoic and overlying Pleistocene (glacial) sediments only to re-emerge at the surface in the vicinity of Philadelphia, Pennsylvania.

In southeastern New York and western Connecticut, the crystalline infrastructure is divided along strike by a steeply oriented, annealed ductile Taconian lithotectonic boundary (Cameron's Line of Rodgers and others, 1959; Rodgers, 1985; Merguerian, 1983a, 1985, 1987) which separates essentially coeval metamorphosed lithofacies of Lower Paleozoic strata. To the east of Cameron's Line, the Hartland Terrane (Ꞓ-Oh in Figure 1) consists of well-layered, amphibolite facies quartzofeldspathic gneiss, schist, amphibolite, and garnet-quartz granofels. This terrane constitutes the remains of former deep-water oceanic sediments and interlayered volcanic rocks deformed in a deep-seated subduction zone and are considered by many workers (Robinson and Hall, 1980; Stanley and Ratcliffe, 1985; Merguerian and Sanders, 1991) correlatives of the Taconic sequence. Taconic rocks, formerly deposited across the slope and rise, are also found to the west of Cameron's line as parts of the Manhattan Schist. (Ꞓ-Om; See below.)

Rocks found to the west of Cameron's Line include the Proterozoic Fordham Gneiss (Yf), consisting of felsic- to mafic gneiss and orthogneiss with lesser biotite schist and diopsidic calc-silicate rock. In Westchester, New York, subunits of the Fordham are unconformably overlain by rocks of the Sauk Sequence (Hall, 1968a, b) including the Cambrian Lowerre Quartzite (Ꞓl) and the Cambrian- to Ordovician Inwood Marble (O-Ꞓi). The Sauk Sequence is disconformably overlain by the Tippecanoe Sequence, here represented by the Manhattan Schist (Om) of presumable mid-Ordovician age (Figure 2). In marked contrast to the former oceanic parentage of the Hartland sequence, together, the western sequence represents former 1.1 Ga continental crust (Yf) and overlying 500-million-year-old shallow-water shelf sediments (Ꞓl + O-Ꞓi = Sauk Sequence) and deeper-water foreland-basin sediments (Om = Tippecanoe Sequence), now metamorphosed to quartzite, marble, gneiss, and schist.

Thus, in NYC the belts of rock originally lumped together as the Manhattan Schist are now interpreted to consist largely of gneissic rock that is structurally imbricated along two major ductile faults. In NYC, the base of the Manhattan Schist (Є-Om) is truncated by a ductile shear zone, named the St. Nicholas thrust (Merguerian, 1995; Merguerian and Baskerville, 1987). Further, the Hartland Terrane (Є-Oh) is in ductile-fault contact with the Manhattan Schist (Є-Om) along Cameron's Line. (See Figures 1 and 2.)

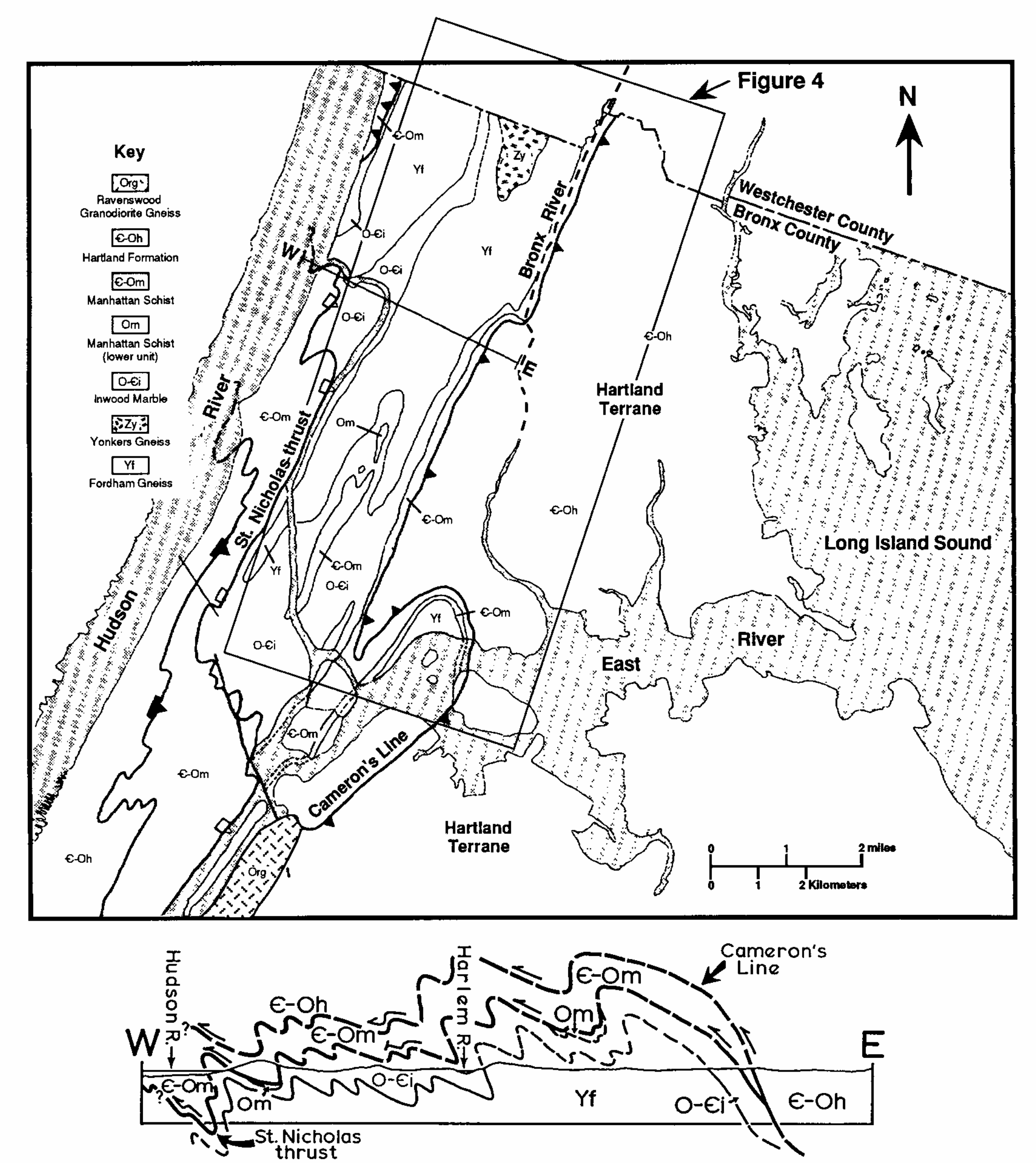

Figure 1. Geologic map of south end of Manhattan Prong showing Cameron's Line, the St. Nicholas thrust, the Hartland Terrane, and the Ravenswood Granodiorite (Org). Rectangle shows location of Figure 4. Geologic section shows stacking of the two Taconian thrusts across the north end of Manhattan eastward to the Bronx. (Adapted from Merguerian and Baskerville, 1987, fig. 3, p. 139.)

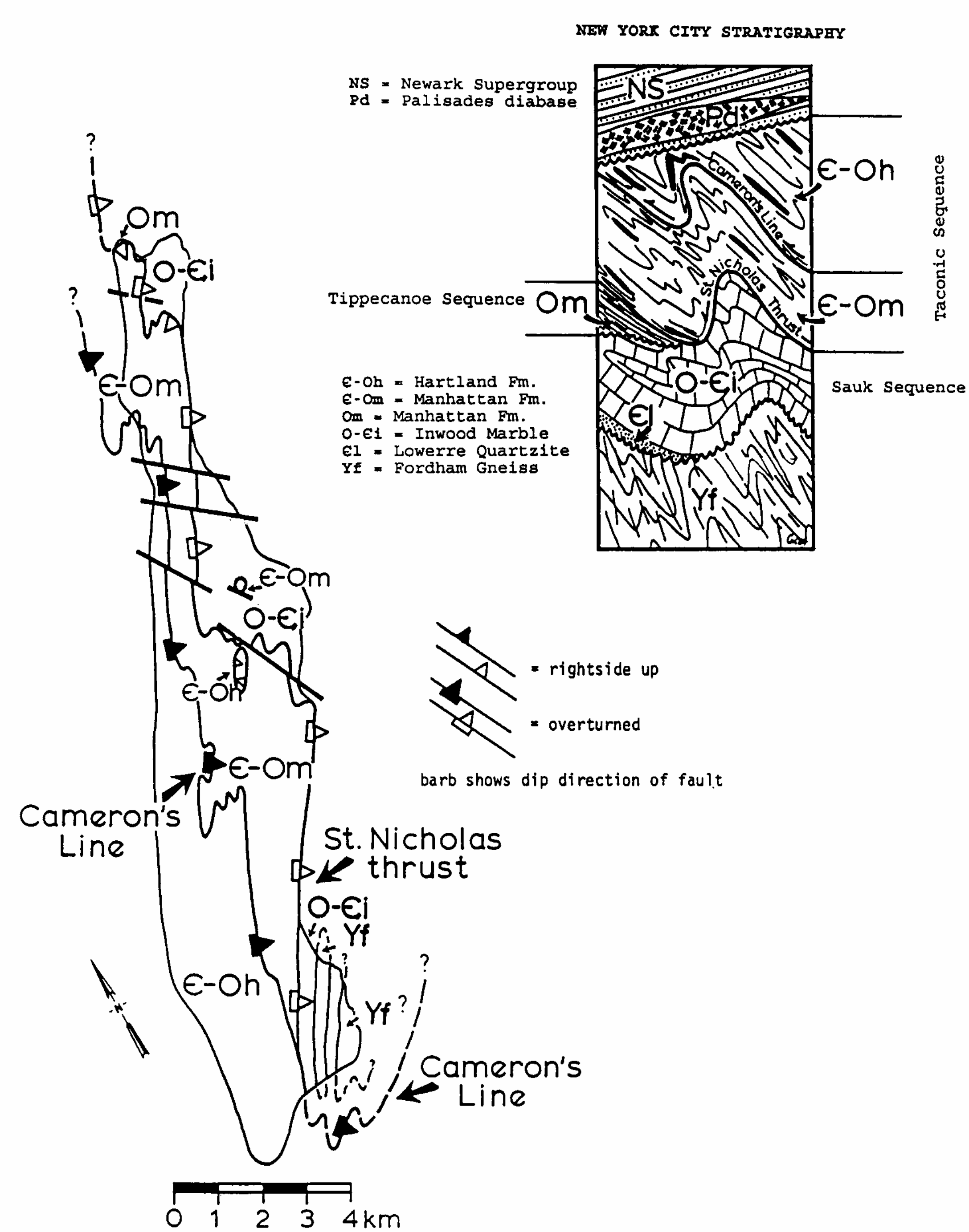

Figure 2. Geologic map of Manhattan Island showing Merguerian's interpretation of the stratigraphy- and structure of the Manhattan Schist, Hartland Terrane, and underlying tectonostratigraphic units. Inset shows schematic geologic column. Text matches formation abbreviations with names of formations. (Merguerian and Sanders, 1991, fig. 20, p. 107.)

STRUCTURAL GEOLOGY OF NEW YORK CITY

In Queens and Brooklyn most of the bedrock is buried beneath roughly three hundred feet of Cretaceous- and Pleistocene sediment yet surface exposures of bedrock are abundant in the Bronx and Manhattan. Rocks exposed in Manhattan and the Bronx consist of amphibolite-facies metamorphic rocks that have been intensely folded (three superposed episodes of isoclinal- to tight folds with products of local shearing and development of related penetrative fabrics and later, at least three lower-grade episodes of folding at elevated crustal levels).

Folds

Mapping in NYC delineates two culminative episodes of superposed isoclinal- and shear folds (F_1+F_2) that resulted in a composite regional foliation (S_1+S_2) in bedrock units. During D_2, a penetrative foliation (S_2) formed axial planar to F_2 folds which produced a large-scale recumbent bedrock structure that strikes N50°W across Manhattan Island and dips 25°SW. (See Figures 1 and 2.) Although the S_2 regional metamorphic grain of the New York City bedrock trends N50°W, the northeast trend of map contacts have been determined by F_3 isoclinal- to tight folds which are overturned toward the northwest and plunge SSE to SW at 25°. S_3 is oriented N30°E and dips 75°SE and varies from a spaced schistosity to a transposition foliation often with the effects of pronounced shearing near F_3 hinges. The F_3 folds and related L_3 lineations mark a period of L-tectonite ductile flow that smeared previously flattened (into S_2) quartz+kyanite lenses and -layers into elongate shapes.

Since their deformation during the early part of the Paleozoic Era, the rocks were subsequently affected by at least three, comparatively weak open- to crenulate folding episodes (obvious folds of the foliation) at significantly lower metamorphic grade and cut by a great number of dominantly steeply dipping brittle faults.

Ductile Faults

Synchronous with D_2, foliated rocks of the Sauk, Tippecanoe, and Taconic sequences were imbricated along two major syntectonic ductile thrust faults (Cameron's Line and the St. Nicholas thrust), and intruded by late-syntectonic calc-alkaline plutons (now orthogneisses such as the Ravenswood Granodiorite Gneiss of Zeigler [1911] (See Figure 1.) and the Brooklyn Injection Gneiss of Berkey [1933, 1948] and Blank [1973]). These metaplutonic rocks vary from granitoids through diorite and lesser gabbro and are typically foliated indicating a relatively early intrusion age with respect to structural deformation and regional shearing.

D_2 shearing along Cameron's Line and the St. Nicholas thrusts and recrystallization during D_3, together produced an annealed, highly laminated mylonitic texture within these fault zones (Merguerian, 1983b, 1988, 1994; Merguerian and Baskerville, 1987). Recrystallized mylonitic layering is identified by ribboned- and locally polygonized quartz, products of lit-par-lit granitization, flattened kyanite-rich nodules and quartzose ribbons, and quartz veins developed parallel to the axial surfaces of F_2 folds.

Brittle Faults

Two contrasting, near-orthogonal brittle-fault sets cut the isoclinally folded imbricate ductile thrusts (Cameron's Line and the St. Nicholas thrust) and amphibolite-facies metamorphic rocks of NYC. Figure 3A, a stereonet of poles to 118 surface faults, shows a bimodal distribution of moderate- to steep faults although a scattering of gently dipping faults exists. This field evidence and existing subsurface data indicate that the trends of these sets are: 1) approximately N30°E (roughly parallel to the overall trend of lithologic units and the axis of Manhattan Island), and, 2) approximately N45°W (across the NE trend, roughly parallel to the N50°W average S_2 axial surface of the F_2 folds). The trends of brittle faults in the vicinity of New York City are the products of emphatic structural control. Regionally, the NE-set parallels the axial surfaces of F_3 folds and the composite lithologic layering (S_0) and F_3 A-C joints and the composite S_2 regional foliation controls the NW set. Features of the two fault sets are summarized below.

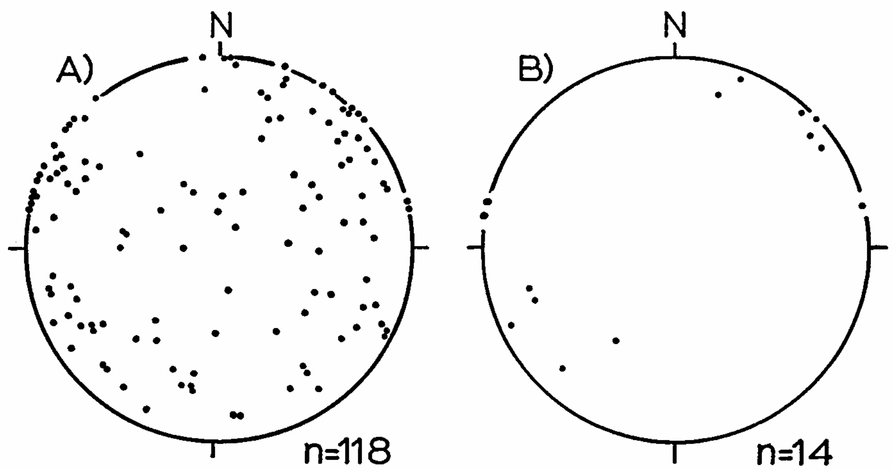

Figure 3. Equal-area stereonets showing poles to mapped surface faults. Northern half of net used for poles to vertical faults. **A)** Poles to 118 faults showing bimodal distribution of NE- and NW-trending fault sets. The dips of the NE-trending set (average trend of N30°E, essentially parallel to the long axis of Manhattan) are steep to moderate. The dips of the NW-trending set (average trend of N45°W) are also steep to moderate.
B) Poles to 14 strike-slip faults with a dominantly NW trend.

NE-trending faults. The NE-trending faults dip steeply to moderately and show dominantly dip-slip motion with offset up to 1 m in zones up to 2 m thick. Locally, where they parallel NE-oriented mylonites (Cameron's Line and the St. Nicholas thrust), they are cataclastic with greenish clay-, calcite-, and zeolite-rich gouge up to 30 cm thick. Commonly, they have been healed by quartz, calcite, or zeolite minerals. Typically, the NE-trending faults are developed parallel to and commonly disrupt an S_3 transposition foliation or spaced schistosity and/or transposed compositional layering and foliation (S_1+S_2).

NW-trending faults. The NW-trending faults also dip steeply to moderately and show complex movement histories dominated both by left- and right-lateral oblique-slip offset often followed by secondary dip-slip or oblique-slip reactivation. The NW-trending faults contain zeolites, calcite, graphite, and sulfides. Composite offsets along the left-lateral faults average a few cm to more than 35 cm but local offset along the right-lateral faults may exceed 100 meters in brecciated zones. Figure 3B shows the poles to 14 strike-slip faults. Of these, 80% were left-lateral and 20% were right-lateral, with the latter producing map-scale offset of mapped contacts.

The NW-trending faults are structurally controlled by an anisotropy produced by A-C joints related to southward-plunging F_3 folds and/or by the NW-trending S_1+S_2 regional metamorphic fabric of the bedrock. Thus, the intersection of these two important sets has cut NYC into fault-bounded blocks. Of the two, the NW-trending faults show the greatest composite offset but both fault sets are found to cut each other, suggesting that they are both potentially active. We argue below that a NW-trending fault displays clear postglacial activity.

GEOLOGIC FACTORS BEARING ON DIVERSION OF THE BRONX RIVER

Several geologic consequences would be associated with any diversion of the Bronx River out of the presumably ready-made course underlain by the Inwood Marble along the wide Webster Avenue strike-valley lowland (Figure 4). If the river did indeed follow the marble lowland SW of the Mosholu Parkway, then some kind of blockage must have prevented it from continuing to do so. During the time when the river's course to the SW down the Webster Avenue lowland was blocked, the water would have been backed up to form a lake. In such a lake, one would expect that some fine sediments would have been deposited. After a new course to the south through the Snuff Mill gorge had been established, water from the lake would have been locked into this new course across the Hartland Terrane, so that even if the blocked Webster Avenue lowland became available, the river would not re-occupy it.

During the Pleistocene Epoch, the New York City region was affected by at least four glaciations (Fuller, 1914; Sanders and Merguerian, 1994). During each, the pre-existing valleys were covered by ice. Valleys trending across the path of flow of the glacier were filled in. Those trending parallel to the direction of ice flow may have been greatly enlarged. Sea level dropped. When the glacier began to retreat, meltwater became abundant. Water cascading through the ice eroded potholes in the subjacent bedrock (Britton, 1882). Local bodies of stagnant ice broken off from the distal margin of the glacier may have blocked local reaches of pre-glacial valleys, thus preventing rivers from flowing in them until after the stagnant ice had melted.

SUBSURFACE RELATIONSHIPS

The records archived in the New York City Office of General Services, Subsurface Branch, contain evidence bearing on the diversion of the Bronx River. Figure 5 is a stratigraphic profile section culled from borings taken across the Bronx River valley from E. 205th Street to Burke Avenue, at a point upstream from the blockage/diversion. Several noteworthy features of these boring records stand out. First of all, at the bottoms of several borings are what probably should be classified as till ("hardpan," "boulders"). Overlying the putative till is pebbly coarse sand. Next above is a thick clay. We infer that this clay was deposited from a lake that formed in connection with the diversion. The clay is both underlain and overlain by coarse +/- pebbly brown sand. Not shown on this section is the deposit of cobbles having an exposed thickness 20 feet in the excavations for the new Bronx River sewer mentioned by Kemp (1897, p. 19).

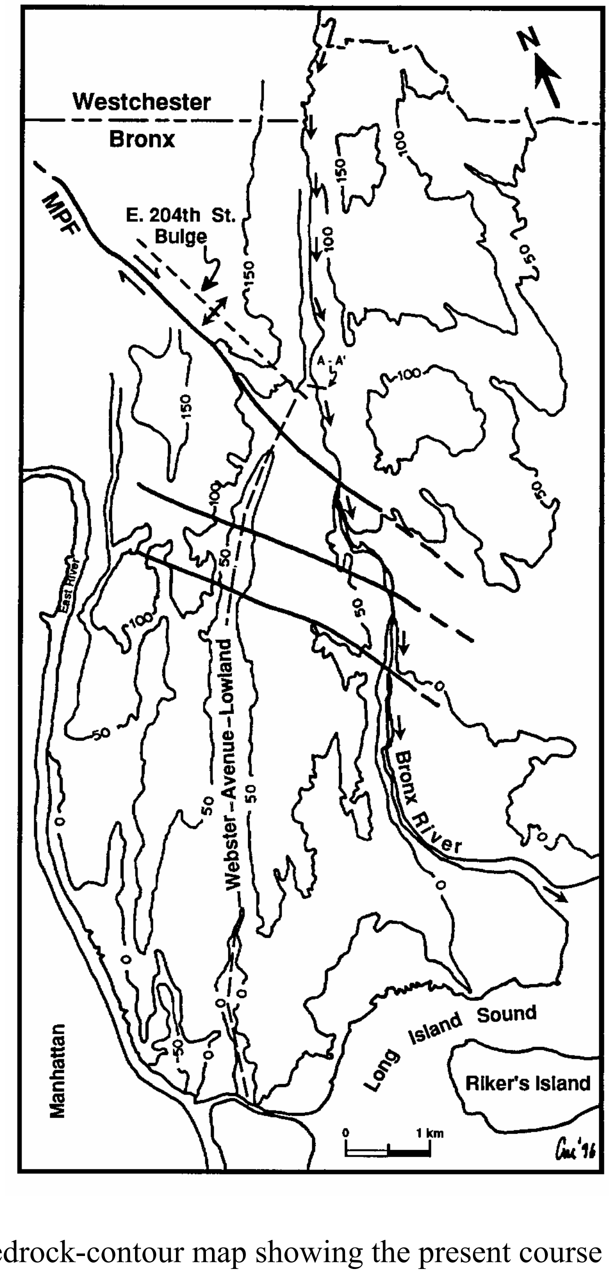

Figure 4. Index- and bedrock-contour map showing the present course of Bronx River, its V-shaped gorge, major NW-trending strike-slip faults including the Mosholu Parkway fault (MPF), the 204th Street Bulge, and section A-A' of Figure 5. The Webster Avenue Lowland marks the previous course of the Bronx River. Subsurface- and fault data from Baskerville (1992), engineering records of the New York City Subsurface Exploration Section, and C. Merguerian (unpublished data).

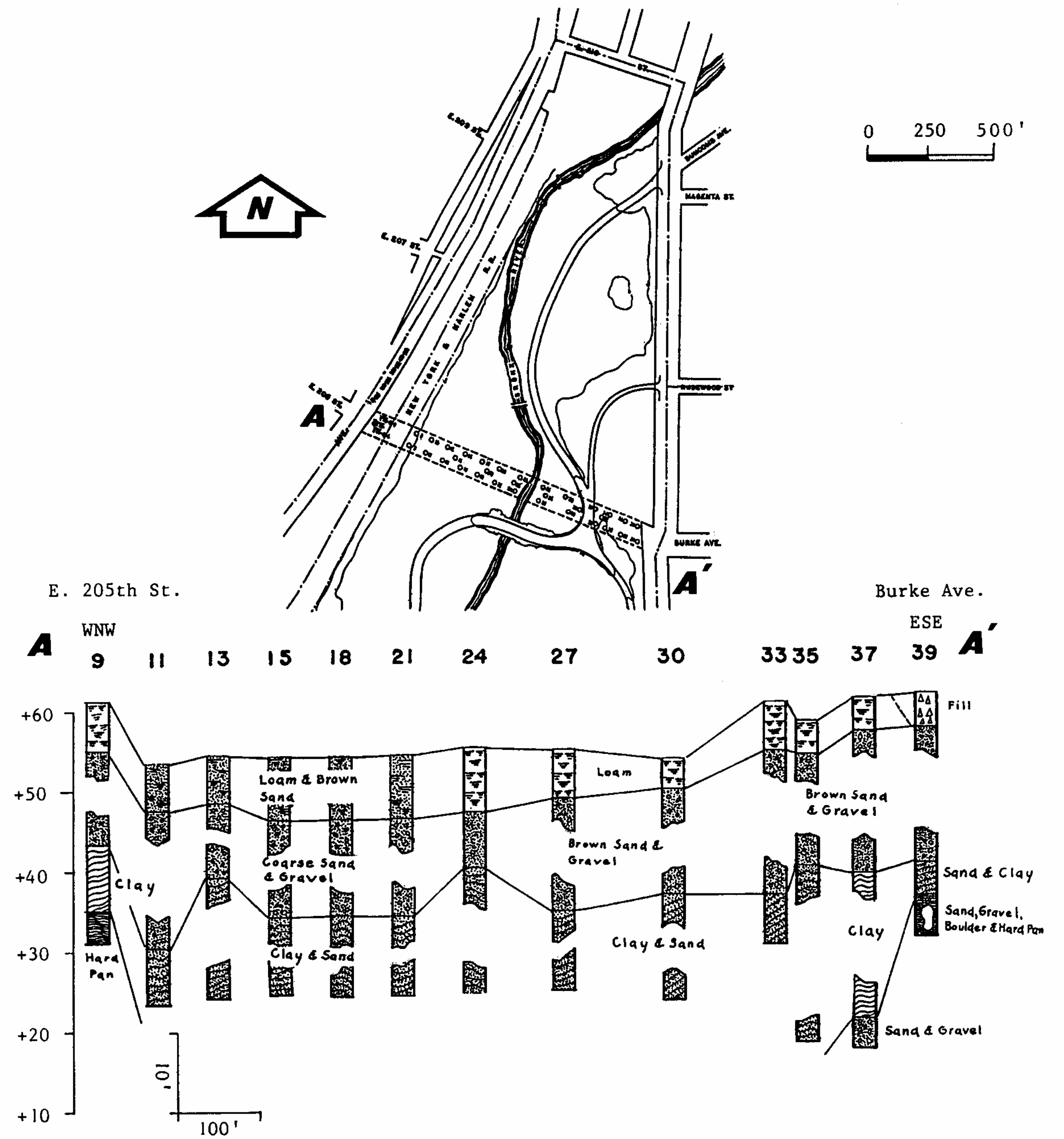

Figure 5. Index map and subsurface stratigraphy from E. 205th Street east-south-eastward to Burke Avenue in the Bronx, upstream of point of diversion of Bronx River based on records of borings assembled in the 1930s by the WPA rock-line map of the Bronx. Line of section shown on Figure 4. Drawn by J. E. Sanders.

A. Index map showing locations of borings and section A-A'.

B. Stratigraphic correlation diagram using original WPA lithologic symbols for individual boring logs. Drawn at 10X vertical exaggeration. Elevations are Bronx Highway Datum.

No clay unit comparable to that found north of the Mosholu Parkway is present in any of the boring records we have examined along the Webster Avenue lowland, where a capping of artificial fill was emplaced before the railroad and streets were built. The records of sediment in the fill of the Webster Avenue valley contain gray sand below, which is overlain by brown sand. Notably absent are any reddish-brown sediments, our key indicators of one- or more pre-Woodfordian glacial episodes (Sanders, 1974; Sanders and Merguerian, 1994, 1995; Merguerian and Sanders, 1991; 1993a, b; 1994). As mentioned above, Figure 4 shows contours on the bedrock surface. Note that the Webster Avenue valley is youthful with a narrow, V-shaped profile.

HYPOTHESES BEARING ON ORIGIN OF THE SNUFF MILL GORGE

We have previously mentioned Kemp's interpretation that the diversion of the Bronx River was a byproduct of Pleistocene glaciation. In this connection, Kemp (1897) entertained four hypotheses as possible causes of the Bronx River's diversion. These are: (1) "a gravel bar or a morainal deposit in the old channel somewhere between Bedford Park Station and tide water;" (2) the present gorge is "an old depression from an earlier period, which perhaps a temporary stoppage of the old channel by the ice sheet had caused the river to clear of possible gravel, etc.;" (3) "during the presence of the ice-sheet (sic), a sub-glacial, or perhaps in part a supra-glacial stream down the upper valley of the Bronx found its way out over this ridge and began to cut it down; being prevented issuing by the old channel because of the presence of the ice;" and (4) "the present channel has always been the drainage line of the Bronx to which it has consistently adhered, while the westerly depression has been caused by the small stream now occupying it; and that the brook has excavated this valley at a little slower rate than the Bronx has its present one."

Kemp reluctantly preferred hypothesis (3). Because he could not find any remnants of a valley-blocking sediment deposit, he rejected hypothesis (1). Likewise, he cited several large, fresh potholes as evidence against hypothesis (2). He cited as his basis for discarding the related hypothesis (4) the small size of the stream flowing in the western valley (our Webster Avenue lowland) compared with the size of this valley. Even though he favored hypothesis (3), he emphasized that: "A lobe of entirely stagnant ice in the old channel as a diverting cause is regarded as an almost too temporary (sic) affair" (Kemp, 1897, p. 22) Kemp concluded that the age of diversion was postglacial.

We fully accept Kemp's postglacial age assignment. However, we do so chiefly for a reason he did not mention, namely that had the Snuff Mill gorge been in existence before the latest glacier arrived in the NYC region, then the ice would surely have changed the transverse profile from its present narrow V shape (See Figure 4.) to a broader U shape and would have polished and striated its bedrock walls. Therefore, we think that the narrow V profile of the Snuff Mill gorge and absence of glacial polishing on the jagged fresh bedrock exposed in the valley walls are powerful arguments in favor of a postglacial age for the origin of the Snuff Mill gorge. As to when the diversion of the Bronx River took place, this would mean no older than about 12,000 years ago.

Given the more-complex history of Pleistocene glaciation of the New York City region than is implied by the advocates of the one-glacier-did-it-all school, at least four glacial advances and -retreats could have been factors in blocking the Bronx River's access to the Webster Avenue lowland (Sanders, 1974; Sanders and Merguerian, 1994; Merguerian and Sanders, 1993a, b; 1994). According to our interpretation of the glacial history, at least two glaciers would have crossed the NNE-SSW-trending lowland and at least two other glaciers (the oldest and youngest) would have flowed down the marble lowland. Retreat toward the NNW of one- or both of the glaciers that flowed to the New York City region from the NNW could have uncovered the part of the marble lowland N of the Mosholu Parkway while ice remained in and blocked the Webster Avenue lowland. This situation could have started the Bronx River flowing across the Hartland Terrane. But the lack of glacial striae on the bedrock walls of the Snuff Mill gorge and the postglacial age of the clay in the valley fill on the E. 205th Street-Burke Avenue section (See Figure 5.) demonstrate that the main cutting of the gorge was postglacial. We find no evidence for fractured bedrock in the Snuff Mill gorge and reject Schuberth's (1968) N-S-trending fault model for river diversion.

We add a fifth hypothesis to Kemp's list of four, namely that postglacial local uplift of a bedrock high (E. 204th Street Bulge of Figure 4.) along the NW-SE-trending Mosholu Parkway fault blocked the marble lowland, dammed the Bronx River, and thus caused a lake to form upstream from the present site of the Mosholu Parkway. Water spilling out of this lake to the south, possibly reoccupying the beginnings of a valley that had been eroded during earlier ice blockage of the Webster Avenue lowland, eroded the N-S-trending Snuff Mill gorge in the New York Botanical Garden, where the Bronx River crosses the Hartland Terrane.

Kemp mentioned a bedrock ledge between the two lowlands, but did not consider tectonic movements among his possible hypotheses of diversion:

"From the entrance to the gorge a swampy depression extends westward to the railroad and has (sic) all the characteristics of an abandoned channel. The railroad has crossed it by an embankment and culvert. Just east of the culvert there is gneiss but a few feet below the soil, and at this point the old stream evidently surmounted a reef."

We think the river did not "surmount" a bedrock "reef," but rather was blocked by it. A bedrock blockage does not face the problem of short time duration associated with ice blockage.

Two points mentioned in Kemp's paper, (a) the deposit of cobbles, 20 feet thick, just south of Williams Bridge; and (b) the high-level potholes in the valley walls of the Snuff Mill gorge merit comment. From Kemp's description, the cobbles postdate the clay and thus may be post-gorge flood deposits. As for the potholes, Kemp inferred that they were associated with torrents of water responsible for eroding the gorge. We prefer an alternative explanation, namely that they were gouged out where individual waterfalls within crevasses in the glacier impinged on the bedrock. If this is correct, then they are older than- and not directly related to the origin of the Snuff Mill gorge.

DIVERSION OF THE BRONX RIVER AS A BYPRODUCT OF MOTION ALONG THE MOSHOLU PARKWAY FAULT

According to Baskerville (1992), the Mosholu Parkway fault (= Van Cortlandt fault of Lobeck [1939] as originally mapped by Merrill and others [1902]) trends NW-SE parallel to the Mosholu Parkway. Baskerville has mapped this fault as being roughly 5.5 km long; his map shows it cutting across the Fordham ridge toward Van Cortlandt Park. The map symbols indicate that Baskerville regards the Mosholu Parkway fault as being a right-lateral strike-slip fault with the north side up. A key factor associated with strike-slip faults is that they displace vertical surfaces. Baskerville's map displays what has to be regarded as an unusual state of affairs: along its extent, the lithologic- and structural contacts that it intersects are not shown as having been offset. Considering the fact that both the fault and the rock-unit contacts it intersects dip steeply, then something about his map is peculiar.

Our studies of subsurface boring records and field examination indicates that the Mosholu Parkway fault is indeed a NW-trending right-lateral oblique-slip fault that projects across the Bronx River channel immmediately below the area (near Webster Avenue and E. 203rd Street in the Bronx) where the Bronx River departs from its previous NNE-SSW-oriented channel and N-S-directed flow begins. (See Figure 4.) A NW-trending bedrock high exists at this point as shown by depth-to-bedrock profiles, topographic maps, and surface exposures. The axis of this basement high (E. 204th Street Bulge) parallels the Mosholu Parkway fault and may, in fact, have been caused by motion along the footwall of the fault. We propose that the northern segment may have moved upward in response to normal oblique-slip motion. Such motion would be identical in orientation and magnitude to offset noted for the subparallel 125th Street fault in Manhattan.

CONCLUSIONS

The anomalous course of the Bronx River through the narrow, N-S-trending, schist-walled Snuff Mill gorge (as contrasted with a course to the SW via the Webster Avenue lowland underlain by the Inwood Marble) resulted from postglacial blockage of the Webster Avenue lowland. A postglacial age is demonstrated by the absence of glacial polishing and -striae on the jagged walls of the Snuff Mill gorge and by a subsurface unit of clay that overlies a probable till in the E. 205th Street-Burke Avenue section. Neotectonic uplift of a block of bedrock adjacent to the Mosholu Parkway fault is thought to be the explanation for the diversion of the Bronx River out of a former course down the Webster Avenue lowland. If our explanation for diversion is correct, we here provide the first evidence for surface deformation in response to faulting in NYC.

ACKNOWLEDGEMENTS

We are indebted to Lawrence Ebbitt and Michael Greenman of the Subsurface Exploration Section, Bureau of Building Design, Department of General Services of the City of New York for their timely help in tracking down archival subsurface information. Dr. J Bret

Bennington of Hofstra University assisted in the computer formatting and labeling of Figures 1 and 4 and Ms. Jessica Levine, also of Hofstra University, assisted in the coloring of figures used in the conference presentation.

REFERENCES

Baskerville, C. A., 1992, Bedrock (sic) and engineering geologic (sic) maps of Bronx County and parts of New York and Queens counties, New York: U. S. Geological Survey Miscellaneous Investigations Series Map I-2003 (scale 1:24,000).

Berkey, C. P., 1933, Engineering geology of the City of New York, p. 77-123 in Berkey, C. P., ed., Guidebook 9, New York Excursions, New York City and vicinity: International Geological Congress, 16th, United States, 1933, Washington, D. C., United States Government Printing Office, 151 p.

Berkey, C. P., 1948, Engineering geology in and around New York, p. 51-66 in Creagh, Agnes, ed., Guidebook of Excursions: Geological Society of America Annual Meeting, 61st, New York City, 135 p.

Blank, H. R., 1973, Observations on the Brooklyn injection gneiss and related formations: New York Academy of Sciences Transactions, series II, v. 35, no. 8, p. 645-660.

Britton, N. L., 1882, On some large potholes near Williamsbridge, New York: New York Academy of Sciences Transactions, v. 1, p. 181-183.

Fuller, M. L., 1914, The geology of Long Island, New York: U. S. Geological Survey Professional Paper 82, 223 p.

Hall, L. M., 1968a, Times of origin and deformation of bedrock in the Manhattan Prong, p. 117-127 in Zen, E-an; White, W. S.; Hadley, J. B.; and Thompson, J. B., Jr., eds., Studies of Appalachian geology, northern and maritime: New York, Wiley-Interscience Publishers, 475 p.

Hall, L. M., 1968b, Bedrock geology in the vicinity of White Plains, New York, Trip A, p. 7-31 in Finks, R. M., ed., Guidebook to Field Excursions: New York State Geological Association Annual Meeting, 40th, Queens College, Flushing, New York: Flushing, NY, Queens College Department of Geology, 253 p.

Kemp, J. F., 1897, The glacial (sic) or postglacial diversion of the Bronx River from its old channel: New York Academy of Sciences Transactions, v. 16 (1896), p. 18-24, map.

Lobeck, A. K., 1939, Geomorphology. An introduction to the study of landscapes: New York and London, McGraw-Hill Book Company, Inc., 731 p.

Merguerian, Charles, 1983a, Tectonic significance of Cameron's Line in the vicinity of the Hodges Complex--an imbricate thrust model for western Connecticut: American Journal of Science, v. 283, p. 341-368.

Merguerian, Charles, 1983b, The structural geology of Manhattan Island, New York City (NYC), New York (abstract): Geological Society of America Abstracts with Programs, v. 15, no. 3, p. 169 (only).

Merguerian, Charles, 1985, Geology in the vicinity of the Hodges Complex and the Tyler Lake granite, West Torrington, Connecticut, p. 411-442 in R. J. Tracy, ed., New England Intercollegiate Geological Conference, 77th, New Haven, Connecticut: Connecticut Geological and Natural History Survey Guidebook No. 6, 590 p.

Merguerian, Charles, 1987, The geology of Cameron's Line, West Torrington, Connecticut, p. 159-164 in Roy, D. C., ed., Northeastern Section of the Geological Society of America, Centennial Fieldguide, Volume 5, 481 p.

Merguerian, Charles, 1988, Annealed mylonitic textures in polyphase deformed metamorphic terrains (abstract): Geological Society of America Abstracts with Programs, v. 20, no. 7, p. A214 (only).

Merguerian, Charles, 1994, Stratigraphy (sic), structural geology (sic), and ductile- and brittle faults of the New York City area (extended abstract), p. 49-56 in Hanson, G. N., chm., Geology of Long Island and metropolitan New York, 23 April 1994: Stony Brook, NY: Stony Brook, NY, Long Island Geologists Program with Abstracts, 165 p.

Merguerian, Charles, 1995, The Taconic problem--alive and well in New York City (NYC) (abstract): Geological Society of America Abstracts with Programs, v. 27, no. 1, p. 68 (only).

Merguerian, Charles; and Baskerville, C. A., 1987, The geology of Manhattan Island and the Bronx, New York City, New York, p. 137-140 in Roy, D. C., ed., Northeastern Section of the Geological Society of America, Centennial Fieldguide, v. 5, 481 p.

Merguerian, Charles; and Sanders, J. E., 1991, Trip 16: Geology of Manhattan and the Bronx, 21 April 1991: New York Academy of Sciences Section of Geological Sciences Trips on the Rocks Guidebook, 141 p.

Merguerian, Charles; and Sanders, J. E., 1993a, Trip 26, Cameron's Line and The Bronx parks, 08 May 1993 (revision of Trip 21, 24 November 1991): New York Academy of Sciences Section of Geological Sciences Trips on the Rocks Guidebook, 126 p.

Merguerian, Charles; and Sanders, J. E., 1993b, Trip 28, Geology of southern Central Park, New York City, 26 September 1993: New York Academy of Sciences Section of Geological Sciences Trips on the Rocks Guidebook, 143 p.

Merguerian, Charles; and Sanders, J. E., 1994, Trip 33, Staten Island and vicinity, 16 October 1994: New York Academy of Sciences 1994 Trips on the Rocks Guidebook, 151 p.

Merrill, F. J. H., and others, 1902, Metamorphic crystalline rocks of the New York City quadrangle, in Merrill, F. J. H.; Darton, N. H.; Hollick, Arthur; Salisbury, R. D.; Dodge, R. E.; Willis, Bailey; and Pressey, H. A., Description of the New York City district: United States Geological Survey Geologic Atlas of the United States, New York City Folio, No. 83, 19 p. (Includes colored geologic map on a scale of l:62,500).

Robinson, Peter; and Hall, L. M., 1980, Tectonic synthesis of southern New England, p. 73-82 in Wones, D. R., ed., International Geological Correlation Project, Proceedings, Project 27: The Caledonides in the U. S. A.: Blacksburg, VA, Virginia Polytechnic Institute and State University Department of Geological Sciences Memoir 2, 329 p.

Rodgers, John, 1985, Bedrock geological map of Connecticut: Hartford, CT, Connecticut Geological and Natural History Survey, Connecticut Natural Resources Atlas Series, scale 1:250,000.

Rodgers, John; Gates, R. M.; and Rosenfeld, J. L., 1959, Explanatory text for the preliminary geological map of Connecticut, 1956: Connecticut Geological and Natural History Survey Bulletin 84, 64 p.

Sanders, J. E., 1974, Geomorphology of the Hudson Estuary, p. 5-38 in Roels, Oswald, ed., Hudson River Colloquium: New York Academy of Sciences Annals, v. 250, 185 p.

Sanders, J. E.; and Merguerian, Charles, 1994, Glacial geology of the New York City region, p. 93-200 in Benimoff, A. I., ed., The geology of Staten Island, New York: Geological Association of New Jersey Annual Meeting, 11th, Somerset, NJ, 14-15 October 1994, Field guide and proceedings, 296 p.

Sanders, J. E. and Merguerian, Charles, 1995, Evidence for pre-Woodfordian ages of Long Island's terminal moraines (extended abstract), p. 91-106 in Hanson, G. N., chm., Geology of Long Island and metropolitan New York, 22 April 1995, Stony Brook, NY: Stony Brook, NY, Long Island Geologists Program with Abstracts, 135 p.

Schuberth, C. J., 1968, The geology of New York City and environs: Garden City, NY, Natural History Press, 304 p.

Stanley, R. S., and Ratcliffe, N. M., 1985, Tectonic synthesis of the Taconian orogeny in western New England: Geological Society of America Bulletin, v. 96, p. 1227-1250.

Ziegler, V., 1911, The Ravenswood granodiorite: New York Academy of Sciences Annals, v. 21, p. 1-10.

Filename: CMJES96a.doc