STRUCTURE AND STRATIGRAPHY OF THE NORMANSKILL GROUP (EARLY MEDIAL ORDOVICIAN) WEST OF THE HUDSON RIVER, TOWN OF LLOYD, ULSTER COUNTY, NEW YORK

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INTRODUCTION

The rocks of the Normanskill Group, formerly included in the Hudson River slates and shales are among the first studied rocks in North America. Notables such as W. W. Mather, Sir William Logan, and James Hall studied the rocks in the mid-Hudson area in the 1830's to 1860's. Because of the complex structure and repetitive stratigraphy of the Normanskill work has progressed slowly, with the most extensive and recent studies being done in the Albany, N.Y. and Quebec areas. In the Mid-Hudson, particularly in Ulster County, the Normanskill rocks have never been adequately mapped, despite extensive exposures along the Hudson River and in area highway and railroad cuts.

Recent fieldwork in the eastern part of the Town of Lloyd has resulted in several discoveries in the Normanskill Group. A relatively diverse shelly fauna has been found in a thick sequence of laminated strata tentatively dating these rocks as post-Austin Glen, but pre-Balmville in age, probably making these the youngest Normanskill rocks yet found. Outcroppings of lower Normanskill aspect (Mt. Merino Formation?), the first seen in this part of Ulster County, have been mapped around Blue Point. Four structural domains have been recognized on the basis of structural and lithologic criteria. Two of the domains apparently cross the Hudson River. Numerous folds and faults have been mapped, some of which show evidences of multiple deformation. Outcrops exposing thick stratigraphic sections have been measured for possible correlation, and excellent sedimentary structures noted in the Austin Glen Formation. Analysis of the data collected during this fieldwork can lead to a more comprehensive understanding of the age relations, sedimentology, stratigraphy, and styles of structural deformation.

TECTONIC SETTING

The Normanskill Group is composed of pelites and turbidites deposited on the basin floor of a trench/foreland basin being transported onto the North American continental margin during early medial Ordovician time. Normanskill sediments apparently were derived from an island arc to the east (Rowley and Kidd, 1981), formed during the attempted subduction of the Laurentian plate beneath the crust of the pre-Atlantic ocean (Iapetus) which lay between Europe and North America. After lithification, the strata were trapped between the two colliding masses causing folding and subsequent shearing into thrust slices. These slices were forced across the foundering coastal platform until they reached their present locations, juxtaposed against autochthonous

sedimentary rocks of Martinsburg - Quassaic - Snake Hill aspect. Today they are seen in prominant outcrops dispersed along the Hudson River, and near Lake Champlain.

STRATIGRAPHY

The Normanskill Group is presently comprised of three formations. The lowermost is the Indian River Formation (Keith, 1932), of Porter-field age, which contains graptolites of the Nemagraptus gracilus zone (Berry, 1962). It contains red and green shales or slates with interbedded red and green cherts attaining a thickness of about 150 feet (46 m.) at Granville, New York. The Indian River Formation probably does not crop out in the Town of Lloyd.

Succeeding, and /or laterally equivalent to the Indian River is the Mt. Merino Formation (Ruedemann, Cook, and Newland, 1942), which also contains graptolites of the Nemagraptus gracilus zone. Most of this formation is a well indurated, green argillite, with interbedded green to brown cherts and siltstones. The upper part of the Mt. Merino Formation is a gray to black shale known to contain numerous graptolites. The upper contact may or may not be conformable with the overlying Austin Glen Formation. The thickness of the type-section at Mt. Merino is about 150 feet (46 m.), but is probably in excess of 300 feet (92 m.)at Blue Point in the Town of Lloyd.

The Austin Glen Formation (Ruedemann, Cook, and Newland, 1942), is of Wilderness age and contains graptolites of the Climactograptus bicornis zone (Berry, 1962). Otherwise it is largely barren of fossils in this area. The formation is composed of thin to medium bedded subgraywackes and shales in the lower portion, and thick bedded graywackes with thin shales in the upper part. Zones of medium bedded graywackes and shales contain as much as 50 per cent $CaCO^3$ by weight and occur in the middle of the formation in the Town of Lloyd and across the Hudson River in the Town of Hyde Park. Thick channel deposits of graywacke can be found at almost any level. Approximately 400 feet (122 m.) of section is exposed at Austin Glen, the type-section, but over 2500 feet (765 m.) of Austin Glen has been measured and described in the eastern limb of a syncline exposed along the western approaches to the Mid-Hudson Bridge and Poughkeepsie railroad bridge (Kruzansky, 1983, Manning, 1983, Boeck and Schimmrich, 1987).

A fourth formation may be proposed for about 3000 feet (916 m.)of laminated shales, siltstones, and sandstones exposed along the eastern flank of the Marlboro Mountains. These rocks contain a locally abundant shelly fauna with a distinctive trilobite population. Tentative identification of these trilobites shows some types common to eastern New York State along with some Proetids resembling those reported from Great Britain. Balmville and later forms appear to be absent. This assemblage would appear to date these rocks as post-Austin Glen, but pre-Balmville, filling a gap in the stratigraphic record of New York State.

SEDIMENTATION

Sedimentologically, the Indian River and Mt. Merino Formations are considered basin deposits with interbedded ash from

island arc volcanism (Rowley, Kidd, and Delano, 1979), while the Austin Glen is probably a distal fan deposit (facies C of Mutti and Lucchi, 1978). The newly mapped laminated strata are likely more distal (facies D). Sedimentary deposits along the western flank of a region of uplift probably supplied the bulk of the sediment found in the Normanskill Group. Density currents carried these sediments westward or southward into the Normans-kill basin. Turbidite sequences show classic graded beds and various parts of Bouma cycles, although locally, coarse pebble conglomerates are relatively rare in the Austin Glen. Sedimentary structures such as flutes, load casts, convoluted bedding, flame structures, and drag marks are seen commonly.

STRUCTURE

Structurally, rocks of the Normanskill Group in this area are thought to be allochthonous, having been transported westward by thrusting during the Hudson River phase of the Taconian orogeny. Locally, the Esopus fault is thought to separate the autochthonous strata (Quassaic Group) from the allochthonous (Normanskill Group). Slaty cleavage, en echelon, sigmoidal, and massive tension gashes, numerous slickensides, drag folds, normal and reverse faults, and thick shear zones are evidence of tectonism. The residual effects of this are seen in four domains which exhibit differences in lithology and style of deformation.

The first domain encompasses an area beginning about 0.5 miles south of Routes 44 and 55 and bounded by Route 9 east of the Hudson River, Route 9W on the west side, and running south to the Town of Marlborough boundary line (figure 1). This domain contains the Mt. Merino exposures which form four probable thrust slices, two on each side of the Hudson River, bounded by massive graywackes of Austin Glen aspect. To the north of these outcrops are more thinly bedded Austin Glen graywackes and shales displaying relatively small scale folds, sheared drag folds, and calcite slickensides on bedding planes which indicate movement from the southeast.

The second domain, which commences 0.5 miles south of Routes 44 and 55, is bounded on the east by the Hudson River, on the west by a fault near Route 9W, and continues north to near Clearwater Road. This area encloses a substantial synformal structure composed of lower middle, and upper Austin Glen lithology. Roadcuts in the area of the Mid-Hudson Bridge expose over 2500 feet (763 m.) of section (Kruzansky, 1983, Manning, 1983), the most ever measured in the Austin Glen Formation. The structure plunges gently about N 5° E and, in areas, shows characteristics of a downward facing structure indicating later reorientation of the syncline. Also within this domain are small wrench faults and folds with sheared hinge lines containing rounded, elongate graywackes enrolled in shale mattrices. Most folds in this domain are recumbent.

The third domain encompasses an area north from Clearwater Road to the Town of Esopus boundary line, and is bounded on the west by a fault zone trending about N 5° E beginning east of Route 9W. On the east, this domain starts on the west bank of the Hudson River and probably crosses the river south of Crum Elbow

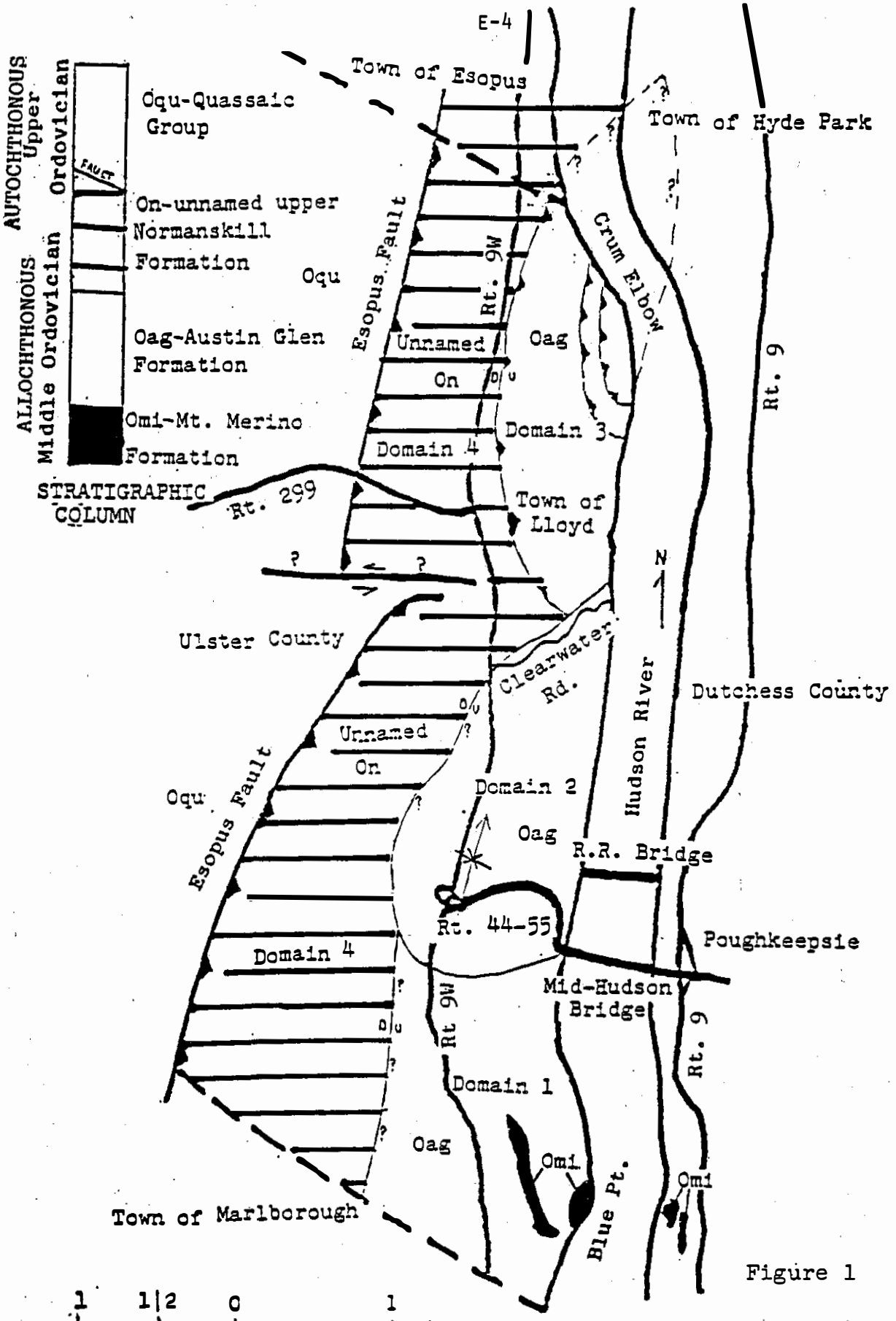

Figure 1

SKETCH MAP OF STRUCTURAL DOMAINS

continuing until it intersects a fault trending obliquely S 45° W through the intersection of the west bank of the Hudson River and the Town of Esopus boundary line, running to the western boundary fault.

This domain is composed largely of upper Austin Glen strata, including several thick graywacke sequences, and medium bedded turbidites containing a large percentage of interstitial $CaCO^3$. Structurally, this area shows numerous imbricated thrust slices which center around Crum Elbow. Strata generally dip southeast, but strikes and dips change rapidly near fault boundaries. Folds near the northern boundary are nearly vertical, plunging steeply northeast.

The fourth domain essentially contains all the area west of a fault zone running approximately parallel to Route 9W, crossing the Hudson River along the north boundary of domain 3. The western boundary is the Esopus Fault running along the lower part of the eastern flank of the Marlboro Mountains except at the north end of Illinois Mountain where the fault apparently has been folded and offset to the east. The southern and northern boundaries of the domain lie outside the Town of Lloyd.

The laminated strata of uppermost Normanskill comprise this domain. These strata are bounded on the west by sandstones of the Quassaic Group (middle to upper Ordovician). Except at the north end of Illinois Mountain these strata largely strike between N-S and N 10° E and are overturned dipping 80° to 87° SE. A few outcrops are upright, dipping 20° to 30° NE. Younging directions are often difficult to determine in these laminated sandstones, siltstones, and shales, and the possibility of isoclinal folding exists, but has not been established in the field. These strata demonstrate more continuity of structure than those in any of the other domains. Possibly this indicates less distance of transport during thrusting. The most impressive structural complication in Domain 4 occurs at the north end of Illinois Mountain where the strike of Quassaic beds turns from the usual N 10° E to E -W indicating a folding of the Esopus fault to the east (Cunningham, 1987). On Illinois Mountain the fault averages about N 15° E in trend, while on the mountain to the north of Route 299 the fault trends about N 5° E. A cross fault trending generally E-W is inferred between the two mountains.

All domains show indications of multiple deformation ranging from the folding and offset of the Esopus Fault, to abrupt changes in orientation of slaty cleavage common throughout the area, to the changes of vergence directions of folds from westward verging recumbent folds to northeast verging, nearly vertical folds in domain 3. Finally, a number of minor faults indicate south to north movement.

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STOP DESCRIPTIONS

Stop 1 Near Mid-Hudson Bridge approach. This road cut exposes rocks of middle to upper Austin Glen lithology, dipping about 45 degrees west. Thick beds of graywacke show massive bedding, and thinner beds expose primary sedimentary structures such as flame structures, convoluted bedding, and cross-lamination. Cleavage dips less steeply than bedding indicating a possible downward facing structure. Looking south into the road cut for the Mid-Hudson Bridge, one can see the most complete section of Austin Glen strata yet measured (Krusansky, 1983, Manning, 1983). This section begins at a fault exposed near the final turn to the bridge, and continues with little interruption to the toll gate. It then continues in a railroad cut until it intersects the center of a N15°W trending syncline. This syncline plunges NE, and covers much of the area in domain 2 (figure 1). Strata from lower to upper Austin Glen is seen in this section.

Stop 2 This outcrop in the vicinity of Johnson Iorio Park contains lower Austin Glen strata. Both the north and south ends are quite deformed with a small reverse fault exposed at the north end, and an intense fault zone at the south end. Numerous graptolites have been found in rock fall near the Park entrance.

Note: The subsequent stops along the railroad are described in order of appearance from south to north. Because access is limited, all outcrops are described, although not all may be visited.

Stop 3 Blue Point. This area consists largely of lower Normanskill strata - probably Mt. Merino Formation. This is the only known exposure of this rock type west of the Hudson River between Kingston and Newburgh. East of the Hudson it is more commonly exposed. This rock is a highly indurated, gray-green argillite with silty or cherty interbeds, and occasional pyrite layers. Gray to black shales are characteristic of the upper part of the formation. It is probably allochthonous with four thrust slices present locally, two on each side of the Hudson (figure 1). These outcrops constrict the river by about 30 per cent (pre-railroad width) accentuating the hardness of this material. The strata generally dip and young northwest except at the north end where it is overturned. It is highly sheared and folded making stratigraphy very difficult. Bedding can be traced by following the cherty or silty layers when the light is 'right'. The southern part of the exposure is green argillite cored by a brown, dolomitic argillite forming an antiformal structure. The middle portion of the outcrop is primarily green argillite while the northern end contains sheared, gray to black shales known from the upper Mt. Merino. Graptolites are commonly found in these shales. To the northwest, the contact with the overlying Austin Glen Formation is probably at the north end of the outcrop where light gray, thin-bedded shales appear. A thin covered zone separates this strata from thick bedded graywackes with thin shales characteristic of the upper Austin Glen. This suggests a major fault trending southwest. The presence of other Mt. Merino outcrops directly across the river at Mine Point raises the question of whether the

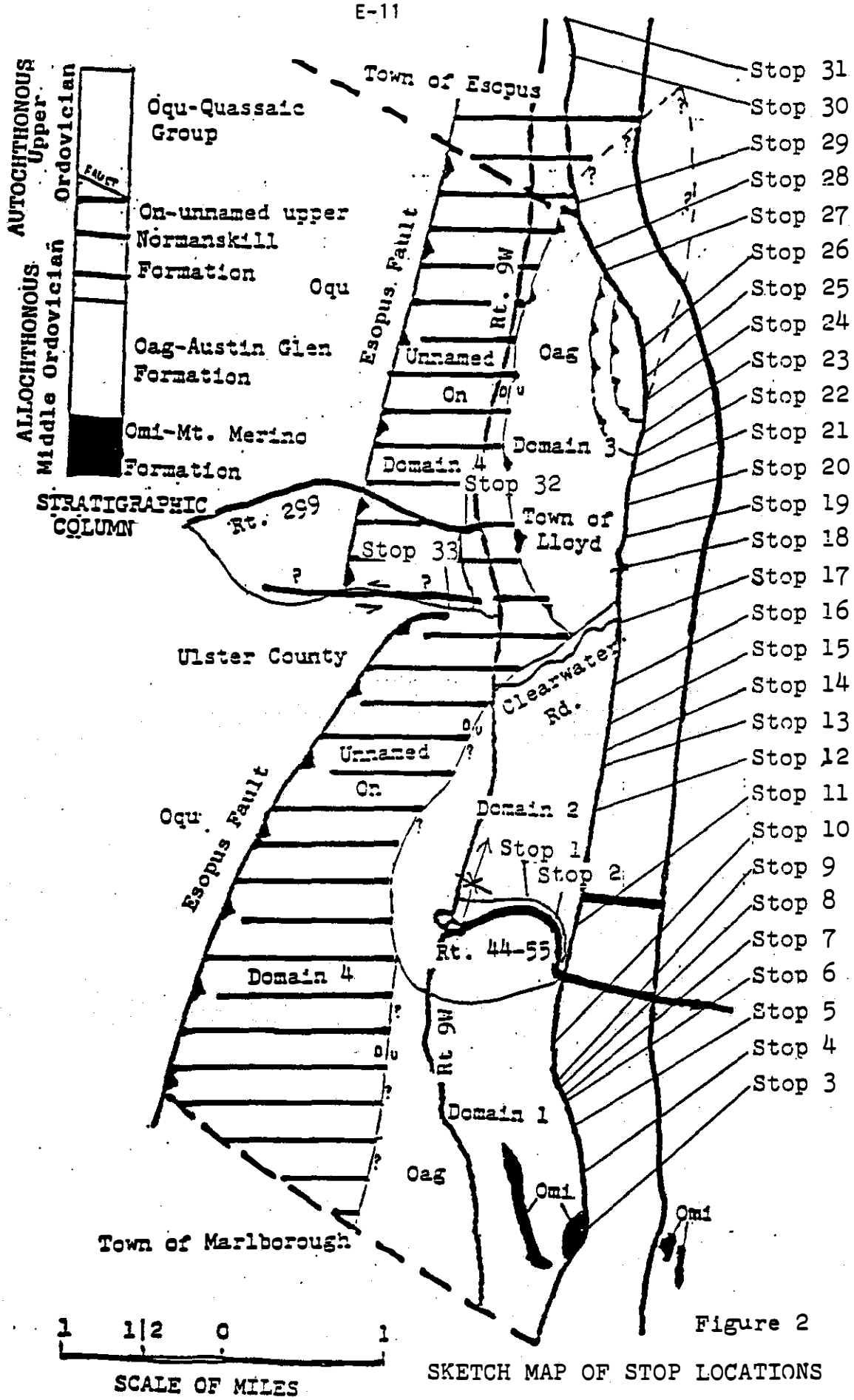

Figure 2

SKETCH MAP OF STOP LOCATIONS

Hudson River is structurally controlled or whether it is a superposed stream. Circumstantial evidence here and to the north at Crum Elbow suggests that this is a superposed stream.

Stop 4 This outcrop contains thick graywacke beds with thin shale interbeds typical of upper Austin Glen lithology. These beds dip northeast and are overturned. Cleavage dips gently southeast. The stream to the south may be a fault trace. If this is so, the fault may have reoriented this strata causing the shallow orientation of the cleavage.

Stop 5 Interbedded gray shales and graywackes averaging 2 to 4 cm. in thickness with occasional calciferous or dolomitic, laminated siltstones comprise this outcrop. The rocks in the upper part of the outcrop dip northwest and may be separated from the lower part by a bedding plane fault. The lower strata dip generally northeast and are more deformed than those above. All strata appear to be overturned.

Stop 6 Here the same lithology is exposed as in Stop 3 except many broken sections of thick graywacke are present in the shales due to tectonic disturbance. These beds are overturned and dip about 25 degrees to the east. Bedding plane slickensides are numerous and are aligned approximately east west.

Stop 7 This section represents strata of middle to upper Austin Glen aspect with thin turbidites at the south end and thick graywackes at the north. These beds are highly deformed with the northern, more massive strata apparently dragged into folds along a fault at the north end. Another fault separates the thick graywackes from thin turbidites at the south end of the outcrop. The overall structure dips northeast with the beds dipping nearly 90 degrees at the south part of the section, decreasing to 40 degrees to the north, and then overturning and dipping 40 degrees southeast at the north end. This outcrop also contains curved tension gashes in the massive graywackes and disarticulated folds of thin graywacke in 'smeared' shales at the south. A thick graywacke surrounded by shales truncates abruptly near the south end. Just north of this outcrop, a tight drag fold of smaller dimensions is exposed.

Stop 8 Medium to thick bedded graywackes are exposed here which are upright, dipping 15 degrees northeast. Higher on the hill, these beds increase in dip and are likely to be separated from those of Stop 6 by a fault in a stream bed.

Stop 9 This outcrop contains black shales with fragmented sandstone layers enrolled in the shales. This outcrop is highly disturbed. Relatively flat-lying beds appears to pin almost vertical graywackes to the hill, while thick shales show pinch and swell structure between graywacke layers. Tension gashes and riedel shears can be seen in this convoluted section.

Stop 10 This exposure of lower Austin Glen contains 1 to 2 cm. thick graywackes and shales. Pyritic graptolites can be found

here. Tight folds have formed in this sheared strata with shale enveloped sandstone fragments indicating the degree of deformation. Strata dip northeast at the south end and northwest at the north end, while the cleavage dips east-southeast at a low angle.

Stop 11 This 1500 foot (460 m.) long section consists of lower to middle Austin Glen lithology south of the Poughkeepsie Railroad bridge, and upper Austin Glen north of the bridge (figure 1). This area offers a good stratigraphic section to compare to that in the Mid-Hudson bridge approach (stop 1), and that seen in the railroad cut north of Crum Elbow (stop 27). Beds 1 to 4 cm. thick of alternating graywackes and shales predominate in the southern strata with well developed (ignore the graffiti) reclining, parasitic folds. These give way to thicker graywackes and shales just south of the bridge. Graptolites were found where a cut was made for cables which cross the Hudson River. Thick beds of graywacke dominate north of the bridge abutment. At the south end of the outcrop the beds dip northeast at 40 degrees, increasing to 53 degrees north of the bridge. This is part of the synclinal structure seen at Stop 1.

Stop 12 Highland Landing. This stop consists of middle to upper Austin Glen strata dipping N65E. A small reverse fault cuts this outcrop and a thrust runs along the upper part. Turbidites averaging 10 cm. in thickness dominate the southern half of this outcrop, while thick turbidites with thin shales constitute the northern part. Flute casts are visible on the undersides of some beds.

Stop 13 A shear zone formed in a failed fold hinge occurs at the south end of this stop. Rounded sandstone blocks enrolled in a shale matrix give good evidence of the shear couple at work here. This commonly happens in the hinges of the recumbent folds found in this area when the rock is stretched beyond its yield point dragging fragments of more competant strata into dismembered folds surrounded by shale. The rocks dip steeply northwest at the south end of the outcrop, but flatten considerably to the north. This is apparently middle Austin Glen lithology.

Stop 14 These thick graywackes with thin shale interbeds characteristic of the upper Austin Glen are overturned, dipping 85 degrees northeast. Convoluted beds and rill patterns show the effects of dewatering of the clay layers due to loading. Note the foliated shale clinging to the bottom of some graywacke beds. Sigmoidal tension gashes show orientation of compressive forces, although block rotation cannot be inferred here. A tight fold seen at the north end leads into another shear zone with fragmented graywackes in a shale matrix.

Stop 15 Here, middle to upper Austin Glen with turbidite beds vary from 3 to 7 m. thick with thin turbidites overlying them. Beds are steeply dipping (NW) with a northeast strike. Sedimentary convoluted beds can be seen at the south end.

Stop 16 This is a steeply dipping limb of a synclinal fold which plunges gently north-northwest. Complementary sets of tension gashes indicates direction of maximum compression. Sedimentary structures include rilled surfaces, cross-cutting tool marks, and to the north a 100 foot long by 60 foot (30 m. x 20 m.) high bed under-surface with large flute casts of bidirectional orientation. Shales are altered in color from black to orange, possibly due to incipient metamorphism. It is unfortunate that this as well as many other important geologic features have been painted over in the name of school spirit, young love, or personal identity

North of this outcrop is a tidal pool indicating the pre-railroad (1878) shoreline. Before the railroads were constructed the Hudson River shoreline was considerably more sinuous.

Stop 17 This outcrop contains more sedimentary structures such as convoluted bedding, parallel, horizontal tool marks and, to the north, curved tool marks. Structural indicators are fibrous calcite slickensides, and tension gashes whose sigma one direction appears to be perpendicular to that of the last stop. Here again, orange weathering shales are seen.

Stop 18 House on river, quarry. This quarry supplied graywacke curbstones for New York City. Near the river these middle to upper Austin Glen graywackes and brown weathering gray shales are quite deformed. Overturned shales are pressed against thick upright turbidites which dip 40 to 75 degrees southwest. In the quarry the beds dip 60 to 70 degrees southeast.

Stop 19 This outcrop contains varying lithologies with thick graywackes underlain and overlain by thin turbidites. Similar sequences are seen at several other outcrops. The south end of this section is a shear zone with folded, dolomitic graywackes enrolled in a shale matrix. Toward the north a thick graywacke is encountered, truncated by a reverse fault forcing thin turbidites around it. Immediately beyond, a thick section of 1 to 3 cm. thick graywackes and shales are displaced by faults every few feet.

Stop 20 Thin turbidites form an antiformal structure. Deformation is similar in style to Stop 19. Here, brittle deformation has resulted in at least 4 steeply dipping, cross-cutting faults. These faults separate the strata into zones with different orientations. At the south end the rocks dip 70 degrees to the east. In the next zone they dip about 30 degrees northeast, then 40 degrees northwest. They then change to 5 degrees to the west, and finally at the north end dip 40 degrees southwest and seem to dissect a north plunging anticline. Numerous tension gashes are exposed at the south end of the structure.

Stop 21 This outcrop begins in thin gray shales and laminated siltstones striking slightly west of north and dipping 65 degrees northeast. Small scale folds are well developed as are joint sets. To the north thick graywackes predominate. Here the beds have

rotated to N35E, exhibiting tension gashes. North of the outcrop is a broken zone probably representing a fault.

Stop 22 Following a shear zone at the south end, the cut exposes thick graywackes with dolomitic, laminated turbidites. These beds strike S80W, and dip 35 degrees northwest. This is the first of two outcrops with this anomalous orientation. These rocks probably form a thrust slice separate from the surrounding rocks. This is probably an upper Austin Glen lithology.

Stop 23 Here is a continuation of the lithology in Stop 22. Thick, massive graywackes contain many rip-up clasts of foliated shale. At the north end of the outcrop laminated, dolomitic sandstones underlie the thick graywacke beds. These rocks strike S85E and dip 23 degrees NE.

Stop 24 These beds are oriented N60E to N40E dipping 40 to 67 degrees NW. This assemblage of rocks is dominated by thin turbidites with 10 to 15 cm. thick shale interbeds. This cut shows very good cleavage development with refraction of cleavage into the graywackes. Cleavage is oriented at N42E by 85 degrees SE. At the north end these turbidites dive under thick graywackes which lay at N85W, dipping 55 degrees, increasing to 90 degrees at the north end.

Stop 25 This outcrop consists of a 7 m. band of (2 to 30 cm.) turbidites underlain and overlain by graywackes up to 5 m. thick in a section totalling 40 m. (Hayden, 1986). Insoluble residue studies of some of these shales have revealed up to 55 per cent $CaCO^3$ by weight (Miller, 1986). This outcrop is extremely similar in lithology and cleavage orientation to those in an outcrop located across the Hudson River the Roosevelt estate, suggesting a continuation of structure across the river. The strata of the outcrop dip southeast at 15 degrees at the south end, flattens in the middle, then steepen to 25 degrees SE at the north end.

Stop 26 Crum Elbow. Here the lithology contains middle Austin Glen with 2 to 15 cm. thick turbidites and occasional thick graywacke beds. Cleavage in this outcrop is N35E dipping 76 SE. Several small thrust faults cause the bedding to splay in several directions at the center of the outcrop. Toward the north end of the outcrop is a kink fold whose axis trends N35E, plunging 73 degrees SE. North of this are lower Austin Glen strata striking N25E, dipping 35 degrees SE. The open valley and stream to the north probably indicate a fault zone.

Stop 27 This road cut contains the best stratigraphic section of lower Austin Glen north of Highland. A fault zone at the south end of the cut is traceable for a couple miles to the south-southeast, and forms the boundary between domains 3 and 4 (figure 1). The north edge of this fault zone contains small drag folds along the last two faults in the fault zone. North of here the strata are overturned, dipping steeply to the east. Thin (1 to 3 cm).

turbidites dominate the youngest part of the section, thick graywackes are common in the middle, and thin turbidites again dominate the north end with a few thick graywackes interspersed. Where outcrop on the east side of the tracks ends, another fault terminates the stratigraphic section. North of this are more complexly deformed rocks of the same type and age.

Stop 28 This cut begins at Mile Marker 76, continues for about 1000 feet (300 m.) and contains repeating, sometimes overturned sections of lower Austin Glen strata. These rocks strike about N25E dipping 74 degrees SE. These turbidites usually are 2 to 15 cm. thick. At the north end the graywackes and shales are highly disturbed with massive sigmoidal tension gashes, and en echelon phacoidal fragments of sandstone surrounded by a shale matrix. The stream is probably another fault trace.

Stop 29 This section is complexly deformed and folds plunge steeply northeast. Beds are alternately upright and overturned. At the south end the bedding is overturned, and forms an undulating, curved surface. Tension gashes are vertically oriented, with a number of en echelon sets exposed. In the middle of the section the beds are generally upright. Boudined calcite slickensides are exposed about in gray shale 12 feet up from the road. A massive tension gash oriented horizontally is over twenty feet long and may bend around the rock mass which it envelopes. At least three generations of vein filling can be identified including milky quartz, white calcite, and late clear calcite. The beds at the north end of this outcrop are overturned and are composed of gray shale and thick graywacke. Flattened flute casts are oriented in a near vertical position.

Stop 30 Here the uppermost Normanskill strata are seen for the first time. These are laminated siltstones and shales (usually less than one cm.) with occasional thicker graywacke layers. Here the beds are overturned, striking N8W and dipping 57 degrees NE. At the south end thick tension gashes are seen in the graywackes. Further north curvi-planar surfaces cut by joint sets are seen. These rocks seem almost 'reptilian' in appearance (curvi-planar with 'scales'). To the north, a thrust fault trace is exposed plunging moderately north. Massive tension gashes are exposed below, and up the cliff face they form large curving cavities. At the north end of the outcrop on the footwall of the fault the rocks are less deformed, although they still exhibit good jointing.

Stop 31 These rocks at Mile Marker 77 contain the same lithology as those in Stop 30; laminated siltstones and phyllitic shales showing good jointing. These beds are oriented N8E and dip 72 degrees SE. The strata, and most of those to the north and west continue for miles striking a few degrees east or west of north and dipping steeply east for the most part.

Stop 32 Rt. 299. These laminated siltstones, sandstones, and shales belong to the uppermost Normanskill strata. Bedding is

variable as this location is near an inferred east-west fault zone. The Esopus fault lies about 3000 feet west of here. Fossil brachiopods are found in the disturbed rock, but the exotic trilobites found further south have not been seen here.

Stop 33 Railroad cut through north end of Illinois Mt. Here the Esopus fault lies to the south with rocks of the upper Ordovician Quassaic Group sitting to the west. These rocks form most of Illinois Mountain, and then bending eastward to form the hill to the northeast. The unnamed rocks of uppermost Normanskill are laminated sandstones, siltstones, and shales. They are seen on the east end of Grand Avenue and along a powerline running along the east side of Illinois Mountain. Numerous small brachiopods are found in these rocks. In the railroad cut rocks of the Slabsides Formation of the Quassaic Group are exposed. These are steeply dipping, medium to thick graywackes with thin shale interbeds. Shale clasts and limestone pebbles are much more common than in the Normanskill strata. Large strophomenid brachiopods are often seen on the bottoms of sandstone beds.

ROAD LOG FOR
STRUCTURE AND STRATIGRAPHY OF THE NORMANSKILL GROUP

This road log covers distances and routes for Stops 1 to 3, 11, 12, and 32, 33. Stops 3 to 31 are along a seven mile reach of the Hudson River accessible only by railraod right-of-way. Driving is prohibited except by permission of Conrail. Stop 3 is at Mile 70 and Stop 31 is at Mile 77. Refer to Figure 2 for locations of these stops. Stops 11 and 12 are on public right-of-way near Highland Landing and are logged here.

Cumulative miles	Miles from last point	Log
0.0		Intersection of Rt. 299 and Exit 18, I-87. Turn right (east) on Rt. 299.
5.2	5.2	Turn right at light onto Rt. 9W south.
7.4	2.2	Turn left at light onto Mile Hill Rd., follow sign toward Johnson Iorio Park. Continue parallel to Mid-Hudson Bridge approach.
8.0	0.6	Stop 1 at outcrop on left with good view of road-cut on right.
8.2	0.2	Continue east to Johnson Iorio Park. Stop 2 encompasses entire ridge on right.
8.4	0.2	Turn around and head west. Turn right on paved road.

8.7	0.2	Turn right on Oakes Rd. by river.
8.9	0.2	Pass under railroad bridge.
9.4	0.5	Pass under Mid-Hudson Bridge.
9.5	0.1	Park and walk to Stop 3 at Blue Point 1.8 miles.
		From Stop 10 walk to car. Turn around and drive north to vicinity of railroad bridge where long outcrop
10.1	0.6	is Stop 11.
10.3	0.2	Drive north on Oakes Rd. to Highland Landing-Mariners Harbor Restaurant Parking lot. Stop 12 across tracks to west.
10.4	0.1	Drive north and park near tracks to visit stops 13-31. This is a 5 mile hike one way. Railroad can also entered from north by driving north on Rt. 9W 5 miles to West Park and take right on Floyd Ackert Rd. Park near overpass of Rt. 9W.
		Return to car and travel west on Main St. Turn
11.3	0.9	right on Grand St.
12.1	0.8	Travel on Grand past side streets to intersection with Rt. 9W. Turn right (north).
13.0	0.9	Turn left at light onto Rt. 299 (west).
13.4	0.4	Pull off onto shoulder and park. Stop 32 on right.
		Resume west on Rt. 299, and turn left onto South
13.7	0.3	Chodikee Lake Rd.
14.5	0.8	Turn right on Old New Paltz Rd.

		Stop 33 Hiking along power line to south will bring you to outcrops of uppermost Normanskill Fm. and exploration of hillside should lead to contact of
14.6	0.1	Quassaic Gp. (Esopus Fault).
16.9	2.4	Drive west on Old New Paltz Rd. Pass over 2 railroad cuts and Pancake Hollow Rd. and several side roads. Turn left (west) on Rt. 299
19.3	2.4	Return to point of origin, intersection of Rt. 299 and I-87.