Structure and Tectonic Significance of Deformed Medial Ordovician Flysch and Melange between Albany and Saratoga Lake and in the Central Hudson Valley, New York

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ABSTRACT

The belt of medial Ordovician deformed flysch west of the traditionally defined Taconic boundary thrust was investigated by detailed mapping in the Capital District, from Albany to Saratoga Lake, and large scale compilation of the central Hudson Valley, between Glens Falls and Middletown. Maps and detailed sections are presented. Mapping recognized a two-fold division into a western belt of folded and faulted flysch and an eastern belt which is dominated by tectonic melange. The Folded and Faulted Flysch unit shows northward fining from greywacke-dominated to shale-dominated. Isoclinal folding and incipient melanges are characteristic in the south, whereas in the north folding is mild and deformation more localized. The boundary of this belt with the melange-dominated belt appears abrupt, but is not well exposed as it coincides in many areas with a Pleistocene/Quaternary filled bedrock valley. A flatlying and unfolded body of black shale within the Folded and Faulted Flysch near Saratoga Lake is anomalous with respect to the lithology and structure of its surroundings.

The melange-dominated part could be subdivided from west to east into Western Exotic Melange, Halfmoon Greywacke Zone (HGZ) and its northern equivalent, Eastern Exotic Melange, Bedded Shale, Flysch Melange and Frontal Exotic Melange. The modifier "exotic" indicates assemblages of non-flysch lithologies within the melange, specifically pale green shale, sideritic mudstone and black chert. Preserved bedding and unusual lithology (abundant and thick greywackes) in the HGZ and its northern equivalent contrast distinctively with the surroundings. The structure of the southern HGZ is a large syncline, of which the eastern limb and hinge is cut by a thrust juxtaposing a complexly deformed terrane. Complex melange exposed along the Mohawk River at Cohoes Gorge is described in detail and recorded in a detailed cross-section. The Flysch Melange, comprised only of shale, siltstone and thin greywackes, has small slices (< 10m) of bedded material in contrast to the Western and Eastern Exotic Melange which have virtually none. The Frontal Exotic Melange has large slices of non-flysch material (<20m) and small bedded flysch slices. All units are inferred to be in thrust contact with each other.

Sedimentologically, paleo-current directions and frequent sets of climbing ripples indicate linear trench topography and reworking by strong contour currents for the deposition of flysch sediments. The assemblage of non-flysch lithologies (mainly black chert, sideritic mudstone and pale green shale) was deposited on the slope/rise of a former passive margin. Coarser, more immature, "exotic" greywacke is probably related to the assemblage of non-flysch lithologies. A difference between "exotic" greywackes and "normal" greywackes is suggested by point counting. Phacoidal cleavage is the dominating structural element. Its average plane and other foliations dip moderately to steeply to the east. It is crosscut by late slickensided veins which are probably still associated with melange formation since they do not occur in the large bedded slices.

The assemblage of non-flysch lithologies must be highly allochthonous and probably some flysch is also. An emplacement model consistent with field relations is proposed. Early in the history of emplacement of the Taconic allochthon a coherent slice of non-flysch lithologies and flysch was added in front of the detached but not completely transported Taconic allochthon. Afterwards little or no more flysch was accreted. The basal detachment essentially overrode the seafloor keeping the non-flysch lithologies and flysch slice at the thrust front. Severe disruption and melange formation resulted. The boundary between Western Exotic Melange and Folded and Faulted Flysch is the trace of the basal detachment. Only towards the final stage of shortening was flysch west of this basal detachment incipiently to mildly transported and deformed, the broad melange detachment imbricated, and younger flysch from below the main basal detachment brought up.

Compilation of geological data between Saratoga Lake and Middletown finds that the belt of deformed flysch is continuous and that the basal detachment can be traced to the south into the Ellenville quadrangle. A piggy-back basin (Quassaic group) and a piece of Taconic allochthon (in the Goshen quadrangle) are tentatively identified. The Frontal Exotic Melange and the Taconic Frontal Thrust are the most continuous features. This continuity confirms suggestions of their late definition by previous workers. Between Saratoga Lake and the New York - Vermont state border, the belt of deformed flysch continues and can be traced into and correlated with the Champlain Thrust system of Vermont.

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During my three-year-stay here in Albany I had the good luck to meet many different people who tried their best to support me in a demanding academic environment and to improve my meager intellectual capabilities. In the way my social and academic environment influenced me and supplied me with ways of thinking and communication, it also helped writing this thesis. My (non-academic) apartment-mates provided me with absolutely stress-free housing conditions, a must in times of mental concentration and piles of waiting dishes. Kenny and Stuart, stay as you are! The same is true for my Austrian, germanist, friends Martina and Harry, who had their part in keeping me open-minded in general (in particular towards heavy smokers) and taught me linguistic essentials. Rolf's geologic enthusiasm convinced me to attempt a mapping project. Hey, keep it! Hopefully you'll have a quick look in here, when you come here some time. Thanks to my Wuerzburg exchange companion in Albany, Susi, who kept things in the right perspective. Chris, admiring grades, improved my confidence. Climbing Chris was an understanding and relaxingly quiet friend, especially after long days during my mapping summer. In Michael, I not only found a compatriot in larger mapping projects with whom I could share some Taconic thoughts, but also a friend showing how to live who you are. Albert and his family provided, for a year, a resourceful pool of great family life. Hard-working Ben was a helpful inspiration during long hours of nightly work. My office-mate YoungDo helped a lot just by good conversation, clear thought and an admirable interest in my work. Thanks! The "human machine-gun" (Bill) Mike was one of the few with whom I could pleasantly indulge in some civilized European thoughts about words, language, bicycling, money, politics, people, the world, religion, anything! Ahoi, Angela, Bruno, Stephan, Steffi, Ana and all I forgot, I hope you know yourself how much I would like to thank you for being helpful friends and co-suffering and -enjoying graduate students.

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Last, but not least, a big and warm "thank you" to my parents who never questioned my choices and gave me all I have.

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in back pocket:

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INTRODUCTION

The theory of moving lithospheric plates and its successful application on the modern earth which explains most of the observed geologic, geomagnetic and seismic world-patterns, had since its postulation a strong impact on the interpretation of rocks of every age. The same period of the history of geology saw also an increasing interest in the structural state of rocks and the dynamics involved to generate it, partly triggered by plate tectonics as it requires a highly dynamic continental crust along plate boundaries and partly due to the fact that the often complex structure of rocks was neglected as a secondary, less useful property by earlier geologists.

Since very early in the history of U.S. geology and geology as a science the Taconic Mountains and the Hudson Lowlands were subjects of interest (Lyell 1854 *in* Skinner 1978, Mather 1838, Hall 1847) owing to their location in the accessible New England states. Pioneering geologists emphasized stratigraphy and integrity of exposed sections, using, if possible, correlation of index fossils as the most useful data for a first survey. The dominant structural style, which was primarily deduced from an established stratigraphy, was one of complex multistage folding in different scales (see cross-sections in the geologic map of Vermont, Doll et al. 1961). Also the existence of a major overthrust along the Hudson River and extending into Quebec was recognized from these biostratigraphic and mapping investigations (Zen 1967). The allochthonous terrane east of this thrust, which was referred to as Logan's Line, was termed the Taconic Klippe.

In the light of the newly developed theory of plate tectonics the regional geology was reevaluated and an appropriate geologic frame developed (Bird and Dewey 1970). A modern model (Rowley and Kidd 1981) and detailed mapping with a structural emphasis (Jacobi 1977, Bosworth 1980, Rowley 1979, 1983, Vollmer 1981, Steinhardt 1983, Bierbrauer 1991, Herrmann 1992) led to a quite different view of the Taconic orogeny and the smaller scale structures. It was shown that shortening was accomplished in a major way by hard rock thrusting of several more coherent slices over larger distances.

It was in this context that W.S.F. Kidd suggested to me a detailed mapping of the presented area and a compilation of geological data west of the major Taconic thrust in the deformed foreland. For this area a modern reevaluation and detailed mapping was lacking and good previously gathered data north and south of it were present (Vollmer 1981, Steinhardt 1983, SUNYA field-camp 1989). Additionally, another system of thrusts to the north seemed to continue south, west of the major Taconic boundary thrust, into the mapped area. Furthermore, sophisticated investigations of the dominant style of deformation in the mapped area were already carried out previously (Bosworth 1982,1984*a*, Xia 1983) and could be applied. Objectives of this study are therefore to present a detailed bedrock map, to test conclusions resulting from these previous investigations, and to generate an integrated picture for a larger belt.

Fieldwork was carried out during the spring semester 1992 and the following summer for about 2 months. About 400 outcrops were visited, the larger ones more thoroughly. Most attention was given to the structural state of the outcropping rocks. The largest outcrops allowed some insight into the km-scale structure, whereas the size of most outcrops restricted interpretations to their local environment.

Bedrock is in general exposed in valley bottoms and walls and by road-cuts. In some areas outcrop is very sparse. The retreat of the last ice sheet left locally thick glacial sediments in this region, which conceal the underlying bedrock. Additionally an extensive preglacial bedrock topography with steep, now filled valleys (Dineen and Hanson 1983) makes it difficult to predict outcrop locations using present day topography. There are, however, some guidelines in doing so, which were found to be useful during the fieldwork. A high degree of branching in tributary systems with low slopes indicate unlithified glacial sediments (see east of Mechanicville and to north of Troy North), whereas straighter valleys are more likely to expose bedrock. The steepness of valley walls is not a good indicator as the running water has managed to cut rapidly into both cover and bedrock. Changes in slope of the valley bottom to steeper values are, in contrast, good indicators of bedrock outcrops at cascades and waterfalls.

In order to find subdividing characteristics in the monotonous shale-greywacke sequences, I tried to cover a maximum of outcrops as their availability is already restricted by the glacial overburden. Using published maps (Ruedemann 1930, Elam 1960, LaFleur 1965) and by extensive field observations a substantial majority of existing outcrops were probably located. Only large outcrops provide the necessary completeness of structural information to be used for substantive regional interpretations. A long road cut along Route 7 from Latham to Troy (1.5 km) with a long bedrock exposure in a valley (1.5 km) not far from it, a 0.5 km-long railroad cut west of Mechanicville, and the very large outcrop along the Mohawk River from its confluence with the Hudson river to near its northern bend at Crescent (4.5 km) - all are more or less across strike - made it possible to put the observations made on smaller outcrops into a larger framework.

There is a certain heterogeneity in the succession of scales, which will be found in this thesis. First there is an introduction into the general tectonic setting, then the main part follows with comments on the mapping with an internally decreasing scale follows, and finally there is a discussion about implications from the mapping and a compilation at an intermediate scale. This is just the consequence of the natural flow of reasoning from the small scale observation to the large scale interpretations supplemented by an overview, for location of the reader in the context of the regional geology.

GEOGRAPHIC DESCRIPTION

The area studied in detail is located on the quadrangles (all NY State, from south to north) Albany, Troy South, Niskayuna, Troy North, Round Lake and Mechanicville. The two bordering quadrangles to the north - Saratoga Springs and Quaker Springs - were examined in a reconnaissance style. The southern part of the Albany quadrangle and the northern part of the adjoining southern quadrangle (Delmar) were mapped in detail by Vollmer (1981). The eastern boundary of the study area is the Taconic Frontal Thrust (sensu Bosworth et al. 1988), as defined by the confining outcrops, the western boundary is the limit of macroscopic compressional deformation or the easternmost appearance of a large normal fault (Bradley and Kidd 1991), and the boundaries to the north and south are the respective limits of the quadrangles. In terms of better known geographic features the boundaries are: to the east the Hudson River, to the west a line through Ballston Lake, to the south Albany and to the north Saratoga Lake.

All of the area belongs to the geomorphic district of the Hudson-Mohawk-Lowlands, at average elevations of about 300 ft, as opposed to the Taconic Highlands to the east. It is characterized by gentle slopes, smooth hills, and long tributaries to the major rivers. Valley walls are usually steep, but the slopes of the streams and rivers that created them are, on the other hand, mostly gentle.

Two large rivers cross the area, the Hudson River from north to south and the Mohawk River from west to east. Other locally important rivers are as follows (from south to north): the Normans Kill, Mill Creek, Wynants Kill, Poesten Kill, Lisha Kill, McDonald Creek, Anthony Kill, Schuyler Kill, Tomhannock Creek, and the Hoosic River. There are three major lakes - Ballston Lake, Round Lake, and Saratoga Lake as the largest.

The area is in general heavily populated and a dense network of streets connects the larger cities and the frequent housing developments in the countryside. Albany, Troy and Mechanicville are located along the Hudson River. The area has a well developed infrastructure which allows easy access by plane (Albany Airport), train (Amtrak station Albany-Rensselaer) and car (Interstate 87, Interstate 90, also Route 7 and Route 9).

TECTONIC SETTING

Bedrock in the studied area is generally composed of medial Ordovician black- and grey shales and siltstones and thicker greywackes which commonly show characteristics of turbidite deposition. This occurrence of typical syntectonic deep water flysch facies is part of a much larger belt with an equivalent facies extending from Newfoundland to Alabama (Williams 1978 *cited in* Vollmer 1981). Derived from the east and diachronously deposited on shelf carbonates, with younger ages of equivalent flysch units to the west, this belt of flysch is related to the emplacement of various allochthonous thrust sheets east of it during the Taconic orogeny.

For western New England, Rowley and Kidd (1981) proposed the following model of the Taconic orogeny based on the regional geology and petrographic studies of greywackes. In medial Ordovician times a volcanic arc or assemblage of volcanic arcs collided with the North American passive margin after closure of the Iapetus ocean over an east-dipping subduction zone. Thrust loading by the advancing accretionary prism and attempted subduction of the North American continent led to rapid subsidence of the carbonate shelf, drowning, and deposition of black shales. The continental rise became involved in the accretion process, thrust-stacked and finally transported as the Taconic Allochthon to its present position. After shelf drowning with diachronous deposition of black shales, the approaching thrust front delivered turbidites into its foredeep and on the black shales. Turbidite deposition was diachronous as well with a younging tendency to the west as the source and receiving trench moved westward with time.

The study area is located in the structural transition zone between undeformed foreland sediments to the west and the Taconic Frontal Thrust. Vollmer (1981) mapped this transition zone in detail south of Albany and concluded that the observed sequence of deformation from open, isoclinal and overturned folding, to heavy disruption and melange-type deformation with rotated fold hinges and pronounced faulting may represent also the orderly **time** sequence of deformation from early to late stages with final incorporation into the thrust stack. This model was based on work in a rather small field area with isolated outcrops. This study offers an opportunity to test Vollmer's hypothesis in an area of the same structural position. Vollmer also found that low-angle thrusts still occur near the limit of deformation to the west, which was already mentioned by

Bosworth (1984*b*), who described the Lock 7 thrust (No. 15) in this field area, and by Ruedemann (1930). Vollmer and Bosworth (1984) compiled a small-scale map which shows melange zones outlining broad thrust faults in this general area. The map pattern suggests continuous thrusts expressed by elongate melange zones which trend parallel to the main Frontal Thrust. This mapping attempts to fill gaps in Bosworth's map and to find out more about the nature of these thrusts. In his compilation of Taconic geology Rowley (1983) attempts to constrain the time of the thrusting and concludes that it is of late post-obduction age (for unclear reasons).

LOCAL GEOLOGY

Stratigraphy

The most recent edition of the geologic map of New York State (Fisher et al. 1970) shows the following stratigraphic divisions of the medial Ordovician sequence, which comprises the bedrock in the field area:

- Austin Glen Formation
- Mt. Merino Formation
- Canajoharie Shale
- Normanskill Shale
- Utica Shale
- Schenectady Formation
- Taconic Melange

These are mainly biostratigraphic units (fig. 1); nonetheless most are associated with certain key lithologies. Austin Glen and Schenectady Fm. consist mainly of thick bedded greywacke turbidites, the Mt. Merino Fm. of typically black, green or red chert, and Utica and Canajoharie Shale of grey and black silt and shale. The recognition of the Taconic Melange unit is solely based on its lithological and structural appearance. The more recent Geological Highway Map (Rogers et al. 1990) reintroduces Snake Hill as a stratigraphic name, which was introduced earlier by Ruedemann (1912). Other often used stratigraphic names are Snake Hill Shale (roughly Canajoharie Shale plus Normanskill Shale) and Normanskill Group (Mt. Merino Fm. plus Austin Glen Fm. in the flysch belt). The Normanskill Group also occurs east of the Frontal Thrust in the Taconic Allochthon, here also including the basal red Indian River Slate.

Each of these names has a long history of differing usage (Zen 1964, Finney and Bergström 1986). This reflects two principal difficulties in assigning relative ages in the field area, structural complexity and diachronous deposition of lithologically monotonous sediments. Diachroneity requires indirect methods such as correlation by zones defined by families of fossils. The fact of frequent faulting and disruption prevents one from determining relative ages in single outcrops (e.g. Rickard and Fisher 1973) and consequently from comparing outcrop ages. Ruedemann (1930) used the Normanskill gorge as a type locality for establishing the biostratigraphic position of his Normanskill Formation. The outcrop shows highly disrupted greywackes with a complex style of deformation (Vollmer 1981) so that stratigraphic relations within the outcrop seem extremely difficult to decipher and age relations to the surrounding outcrops are obscured by the frequent occurrence of faults. These difficulties lead one to focus on the problems of proper correlation by fossils using a stratigraphy obtained outside this area. Two principal questions may be asked for this purpose. Is the biostratigraphy correct? And, is the correlation correct? For the stratigraphic question such topics as the application of principle of superposition, definition of fossil zones of a certain age, 'internal' correlation between large intact sections in the defining area, or plausibility of evolutionary lines are important. In contrast, for the correlation question, topics such as geographic and climatic provinciality of fossil groups, incompatibility of the inferred age relations with the local geology, or lack of sufficient fossil information should be considered. In view of these aspects Riva's (1974) zonation of the Medial Ordovician has been shown to be the most useful, mainly because it is based on observations in geologically closely related areas.

Vollmer (1981) provides a figure, which shows Riva's zonation (1974), Fischer's stratigraphy (1977) and Ruedemann's stratigraphy (1930) in an attempt of correlation. It is reproduced here (fig. 1) because it gives a compact summary of usage of names and their interrelation.

In a detailed study of complete sections in the Arbuckle and Ouachita mountains, Oklahoma, and of graptolite collections from Kentucky, Finney (1986) revised, the graptolite zonation of Riva (fig. 2). Finney cannot recognize a *D. multidens* zone as Riva does, but reintroduces a similar *C. bicornis* zone. Both, Riva's *D. multidens* and Finney's *C. bicornis* follow immediately the older *N. gracilis* zone and are immediately followed by the base of the *C. americanus* zone in the northern Appalachians (Riva 1974) or the equivalent base of the *O. amplexicaulis* zone in the region Finney studied. The difference between Riva's and Finney's zonations is in essence that the *gracilis/bicornis* boundary is slightly older than the *gracilis/multidens* boundary and, more importantly, that Riva

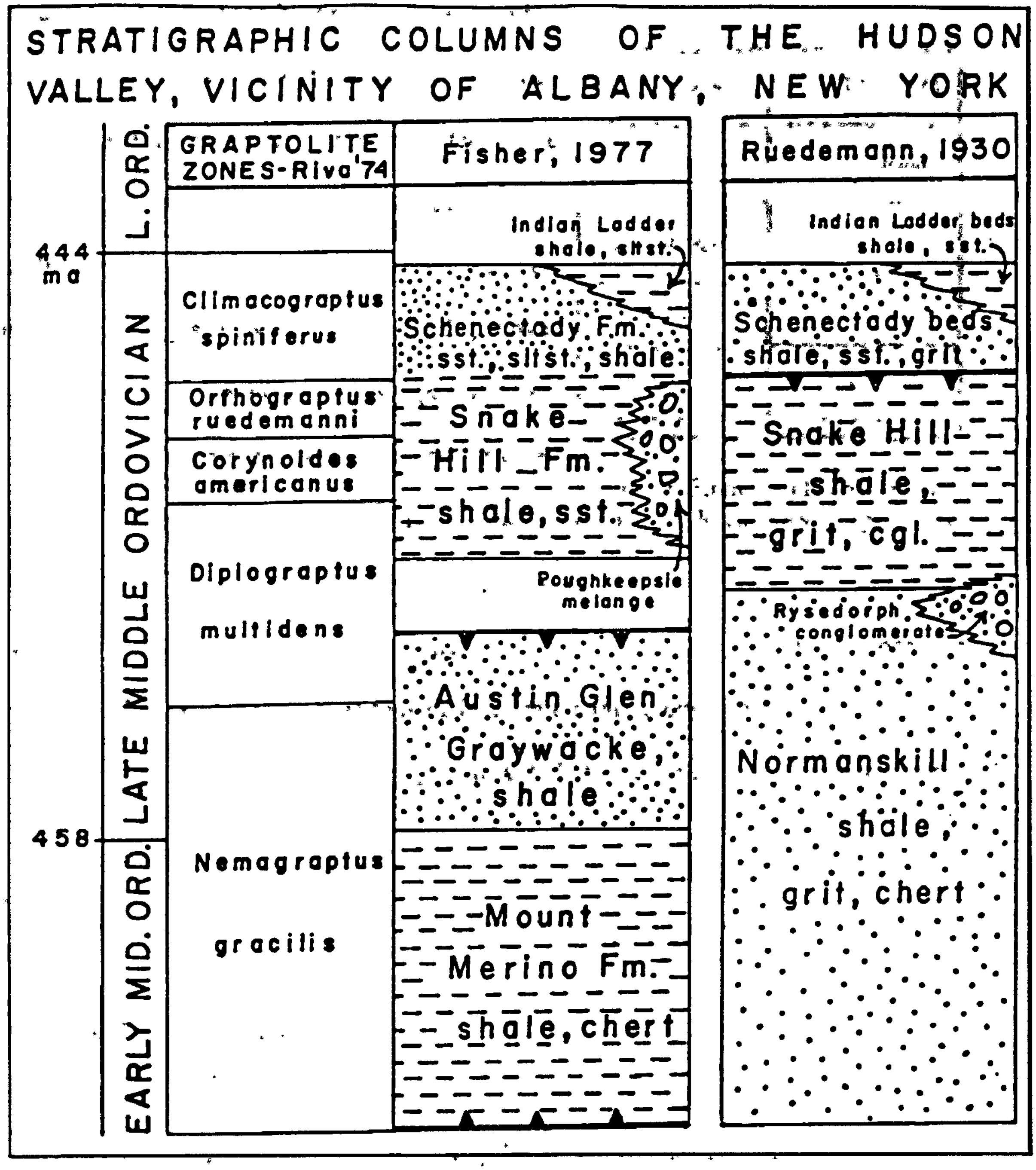

Figure 1 Riva's graptolite zones and stratigraphic units (from Vollmer 1981, corrected for misspelling of *ruedemanni*).

included *bicornis* fauna in his *gracilis* zone. In other words, Finney demonstrates that in his continuous sections there is no space for a *multidens* zone between a *gracilis* zone and younger zones. This has the effect that rocks assigned to *gracilis* zone age by Riva's assemblages may be in fact of younger *bicornis* age. Younger zones (*americanus, ruedemanni, spiniferus, pygmaeus)* are not affected by Finney's revision. Despite the *multidens* discrepancy, I believe it is still preferable to use Riva's graptolite zonation because it was derived in a geologically and spatially close area and because long distance comparisons of fine-scale stratigraphy should be viewed very cautiously in view of the large spatial gaps in data between widely separated sections.

<table>
<tr><th>RIVA (1974)</th><th>FINNEY (1986)</th></tr>
<tr><td><i>C. americanus</i></td><td><i>O. amplexicaulis</i></td></tr>
<tr><td><i>D. multidens</i></td><td rowspan="2"><i>C. bicornis</i></td></tr>
<tr><td rowspan="2"><i>N. gracilis</i></td></tr>
<tr><td><i>N. gracilis</i></td></tr>
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Figure 2 Finney's (1986) revision of part of Riva's (1974) graptolite zonation.

Previous Mapping

Ruedemann's Map (1930)

Ruedemann published in 1930 a map "Geology of the Capital District", which includes the present field area and is supplemented by an extensive accompanying explanation. He emphasized the paleontological and stratigraphic aspects, but included also a structural description. Since Ruedemann's map is difficult to access, I included a copy of the part which contains my detailed field area in the map pocket.

Ruedemann's Units

Ruedemann distinguished four different units in the mapping area. According to the legend on his map these are from oldest to youngest:

1) Normanskill shale: dark shale alternating with many grit and chert beds, including Ryesdorph Hill conglomerate on top

2) Snake Hill shale: dark shale, some grit and conglomerate

3) Canajoharie shale: black shale

4) Schenectady beds: alternating shale and sandstone

He uses mainly faunal associations to define these units, but describes them also as lithologically distinct. From these unclear definitions confusion often results, particularly for the Normanskill, and within it the Austin Glen.

Ruedemann's Structure

Ruedemann recognized the general strike of about 020° and nearly exclusive eastward dips, frequent isoclinal folding, a gradual decrease in the degree of deformation to the west, thrust faulting extending up to the western limit of deformation, two major thrusts - one at the limit of deformation in the form of a concentration of smaller thrusts and one separating his Normanskill beds from the Snake Hill beds - and the general nature of the local structure as a "schuppenstructure". He also defined two qualitative "isogrades" of deformation, the western boundary of "intense Taconic folding" and the western boundary of "distinct Taconic folding".

Vollmer's Map (1981)

In his work for his master's thesis, Vollmer mapped the area south of Albany extending from the Helderberg escarpment of the Devonian Helderberg Group to the Hudson River. It joins with the area I have mapped and is located in the same belt of structural transition between the Taconic Frontal Thrust and undeformed foreland. His work deals with the structural complexities of this belt. Particular attention was paid to the Taconic Melange.

Vollmer's Units

The mapping led Vollmer to refine the previously defined biostratigraphic units (Ruedemann 1930), using detailed structural information to introduce seven lithostructural units. These are grouped from west to east into Taconic flysch which comprises an unfolded unit; a faulted and folded, but bedded unit; disrupted Taconic melange in a western belt; and an eastern belt. There is also a local melange variety with an especially complex type of polyphase deformation (Normanskill melànge), and blocks and sheets within the Taconic melange which consist of Austin Glen greywacke and Mount Merino chert.

Vollmer's Structure

Vollmer paid particular attention to the melange. He found evidence against the previously proposed soft sediment deformation for the formation of melange, and much evidence suggesting hard rock thrusting: folded extensional veins, brittle failure in fold hinges, axial plane cleavage which cuts veins, consistent axial plane orientation, and absence of any criteria for soft sediment deformation (sedimentary truncations of folds, intrabedding folds) (Vollmer 1981, p. 100)

His main results concerning the structural geology of his field area are:

- phacoidal cleavage: shear origin by down-dip striations, generally associated with thrusts and asymmetric folds, parallel to inferred principal flattening, not parallel to shear plane;
- slickensides: show SE-directed-striations, and in the Glenmont chert slice, steps which indicate thrust sense;
- faults: melange as fault zone, the chert being a hard fault sliver ;
- fold hinge line orientation: some are steeply east dipping; assuming they were originally horizontal and parallel to the regional strike, he explains the unusual orientation by rotation of linear elements into the principal elongation direction under homogeneous strain or along strike strain gradients or both. The high degree of rotation requires high shear strain (prob. $\gamma > 14$).

By detailed and extensive measurement of structural elements in the broad Taconic melange belt he inferred that its appearance in texture and lithology is mainly a product of tectonic processes associated with thrusting and probably high strains. To explain the absence of discretely defined faults in the melange belt and the ubiquitous compressive deformation, he concludes that the melange itself represents a broad fault zone, which includes blocks and slivers of distinctly less deformed, but possibly far travelled material. An olistostromic deposit and complex structural relations in the Normanskill Gorge melange, which may indicate slumping suggested to him that sedimentary processes were included in the tectonically-dominated formation of melange. Along subaequous fault scarps, possibly already deformed material and older lithologies became exposed, eroded, deposited and then were overridden by thrusts to recycle them into the accreting melange wedge (fig. 3).

Vollmer tries to identify a sequence of deformation by correlating the lateral succession of different degrees of increasing deformation from west to east with a time span from earlier to later. He suggests that the present structure now represents the final frozen state of a structural continuum in which more eastern structures are a product of overprinting more western structures. On the other hand thereit can be observed that: he groups outcrops into domains, that inter-outcrop distances are large relative to their size in his map region, and that large strain discontinuities are described in the melange belt. These observations hint perhaps at less connected structural belts with separated properties which cannot be interpreted as one continuum. In the view of this potential discrepancy I tried to find more evidence for or against his proposal.

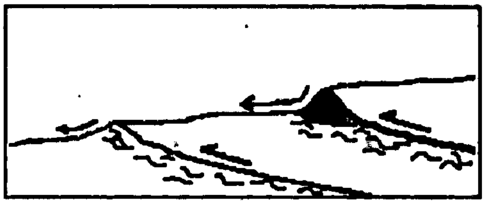

Figure 3 Melange formation as tectono-sedimentary process (after Vollmer 1981)

Elam's Map (1960)

Elam's mapping of the Troy South and East Greenbush quadrangles overlaps with this mapping in the area west of the Taconic Frontal Thrust (Logan's line) in the Troy South quadrangle. Elam's outcrop map was utilized to find exposures and found to be accurate, within the limits of incomplete outcrop preservation in the 32-year-interval since his field work. I included a copy of the part of his map which overlaps mine, in the map pocket.

Elam's Units

Elam distinguishes, in the area of his map which overlaps mine, between the Snake Hill Formation and the Normanskill Formation. Following Ruedemann (1942) and Craddock (1957), the older Normanskill Formation is divided from bottom to top into a Red Shale member ("red shale and quartzite", now Indian River Slate), a Mt. Merino member ("black, green and red chert and black shale") and an Austin Glen member ("greywacke and grey shale"). The Red Shale member is found only east of the Taconic Frontal Thrust. His Snake Hill Formation consists of a lower member consisting of "grey shale and subgreywacke" and an upper member consisting of "silvery grey shale with large slide blocks of chert and Ryesdorph conglomerate". All outcrops show such highly distorted rocks that "stratigraphic measurement is virtually impossible" (which Elam attempts anyway).

Elam's Structure

The Austin Glen member and the lower member of the Snake Hill Formation define thrust slices on his map west of Logan's line. Bedrock west of these slices is assigned to the upper member of the Snake Hill Formation. The Mt. Merino member of the Normanskill Formation is shown as blocks within this unit.

Lithostructural Units

In the course of the fieldwork rocks were grouped into several units having similar lithological and structural facies. No attention was paid to possible faunal similarities. These units do not necessarily correspond to stratigraphic units. It was not possible to establish a stratigraphic column based on information inside the present area. This is why a geometrical lithostructural approach is preferred. In the following description of the units the characteristic lithologies, important outcrops, the corresponding structural features and previous age assignments are included. Where enough fossil data are known, age ranges in terms of graptolite zones after Riva (1974) are given. Age assignments in the melange belt are complicated by the difficulties of distinguishing between block and matrix in a recycled tectono-sedimentary unit. Fossil ages in the melange are therefore in many cases maximum ages as they possibly belong to introduced blocks or slivers.

The lithostructural units occur in belts trending about parallel to the regional strike. The degree of deformation generally increases from west to east. From west to east the bedrock is divided into the following, more formal units with descriptive names:

- Undeformed Flysch: Southern Thick Greywacke, and Northern Shale;
- Folded and Faulted Thin Greywacke, Siltstone and Shale;
- Western Exotic Melange;
- Folded Thick bedded Greywacke (Halfmoon Greywacke Zone);
- Eastern Exotic Melange;
- Bedded Shale;

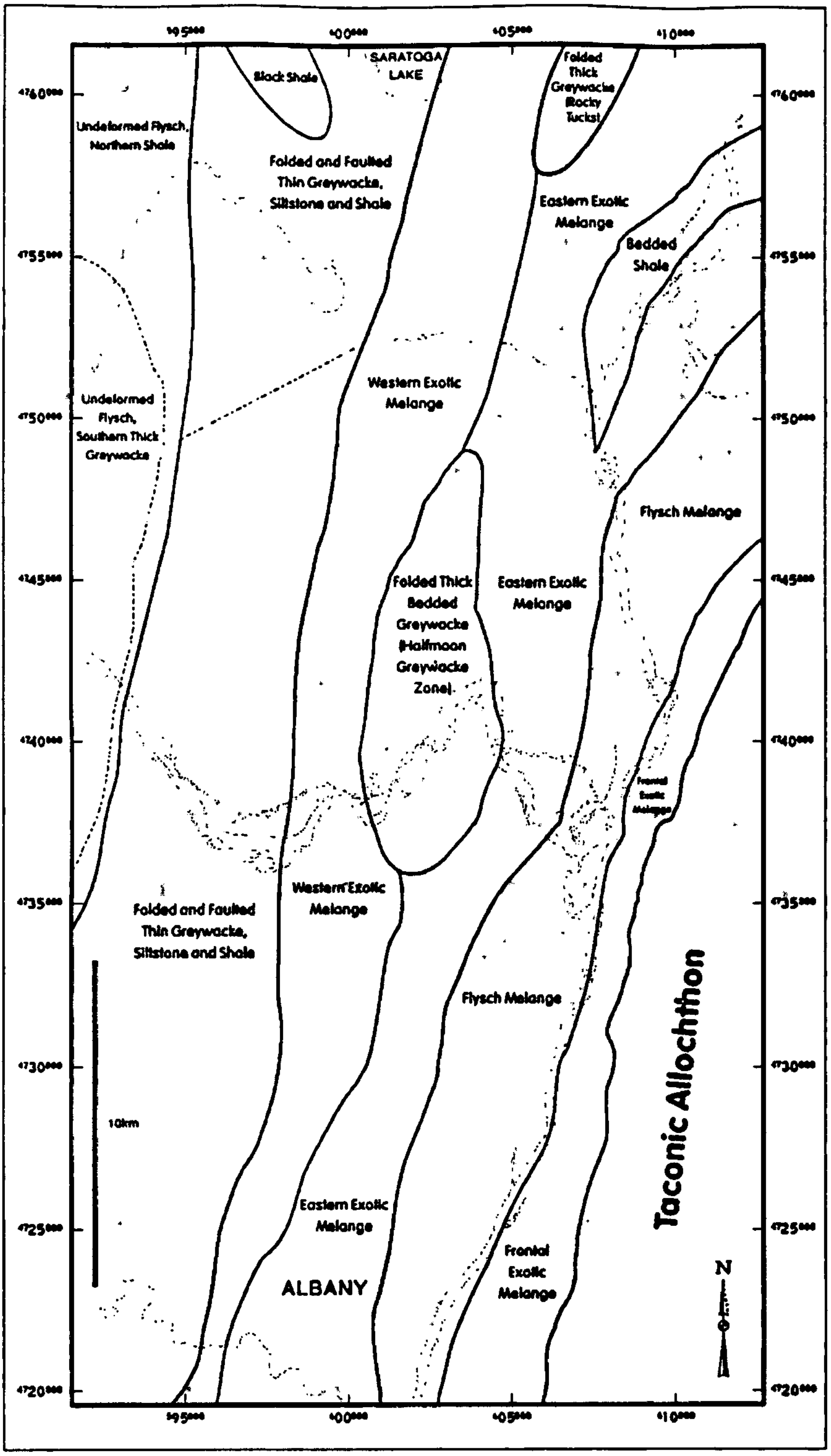

Figure 4 This map shows names of lithostructural units between Albany and Saratoga Lake.

- Flysch Melange;
- Frontal Exotic Melange;

The term "exotic melange" refers to a melange which bears blocks of lithologies that are not found elsewhere in the shale-siltstone-greywacke flysch, particularly, in places, large occurrences of Mt. Merino chert. In order to keep track of these, somewhat similar sounding units, a simple overview map (fig. 4) is provided which shows the position of these units.

Undeformed Flysch, Southern Thick Greywacke and Northern Shale

At the western limit of the mapping area a belt consisting of dm to one meter thick greywacke beds with little interbedded shale and compact dark shale is defined by outcrops 10,15,22,330[1] and 32-36. Strata are everywhere only slightly dipping to flatlying and unfaulted.

Contact within the unit

Along the Mohawk River outcrops 10 (fig. 5) and 15 provide exposures of the contact between the compact thick greywackes with underlying dark shales and siltstones to the east. Outcrop 10 is only accessible from the river and was observed from across

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[1] Outcrop numbers refer to the accompanying outcrop map. In the following just the number is given.

the river. It appears that the lithological change which defines the contact is planar, sharp and abrupt. The gently west-dipping attitude of the strata does not change crossing the contact. The contact at outcrop 15 is not directly accessible but the approximately 0.5m to 1.0m thick greywacke beds close to it are mildly fractured and faulted. To the north outcrops along Ballston Lake show thinner cm-thick greywackes with larger portions of shale, which suggests a transitional contact to the siltstones further north at Ballston Lake (264, 38, 377) and Mourning Kill (81). Overall these relations indicate an essentially conformable boundary between upper thick greywackes, which fine laterally into siltstones and shale in the north, and underlying dark shales. The contact may have been locally accentuated by some faulting. According to the described field relations the contact is indicated on the map as a sedimentary lithological contact within the lithostructural unit considered.

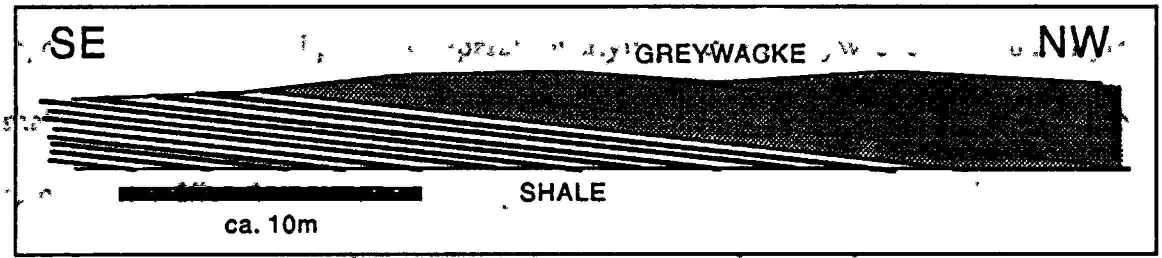


Figure 5 Thick greywackes overlie shale and siltstone at outcrop 10 (looking southwest).

Boundary with Folded and Faulted Thin Greywacke, Siltstone and Shale

The boundary to the eastern Folded Thin and Faulted Greywacke, Siltstone and Shale unit is defined by a change in the structural appearance, not by a lithological break, even if the latter is very distinct. The boundary is described in more detail in the description of the Folded and Faulted Thin Greywacke, Siltstone and Shale.

Similar boundaries described in older publications

Ruedemann (1930) recognized a similar boundary between his Schenectady Beds and Snake Hill Beds and placed the same boundary (interpreted as thrust) at about the same position, but more to the east into more strongly deformed siltstones and shales. He explains the thrust nature of the contact as a simplification of the observation of a multitude of thrusts with small displacements within his Snake Hill Beds (Ruedemann 1930). Ruedemann apparently included in his Schenectady Beds the black shale and siltstone east of the clearly defined lithological break. This is unnecessary, because this break is distinct; a graptolite-based assignment of the shale/siltstone part to his Schenectady beds used in a biostratigraphic sense is speculative in the absence of a reported fossil locality. I prefer to separate overlying massive greywackes from underlying shale/siltstone and to assign them to Schenectady and Frankfort or Utica Formation respectively. His observation of a higher degree of deformation, including frequent thrusting to the east in his Snake Hill Beds, is accurate. His conclusion then to treat the shale mass as a formerly spatially continuous unit which was imbricated and thrusted *en bloc* to the west is consistent with this observation and also with the suggested modification.

The 1970 New York State 1:250 000 map (FIsher et al. 1970) shows the same boundary here between the Schenectady Formation and the Canajoharie Shale to the east as unfaulted and crossing the Mohawk at about the same location as indicated on my map. It fails to show the deformed nature of bedrock east of this boundary. On this map, the outcrops east of Ballston Lake containing thick greywacke are not shown as Schenectady Formation, for reasons not apparent.

Vollmer's (1981) boundary between interbedded, unfolded flysch and mainly interbedded, gently to more strongly folded flysch lies along the projection of this contact along strike to the south.

The geological highway map of the NYSGS (1990) shows no geological boundary which would correspond with any of the above probably due to generalization at the small scale (1:1 000 000).

Graptolites and age

The Schenectady Formation is mainly of *Climacograptus spiniferus* zone age (Riva 1974, Fisher 1977) which is the youngest graptolite zone within the Taconic flysch.

Folded and Faulted Thin Greywacke, Siltstone and Shale

Outcrops along the Mohawk River (4-15), Lisha Kill (3), Elnora Creek (331), east of northern Ballston Lake (38, 264, 377), west of Round Lake (37), along Ballston Creek (372-374, 378, 333, 39, 40, 261-263, 332, 255-258, 41-42), east of Round Lake (49, 196, 254, 197) and at the western shore of Saratoga Lake (35, 48), and along Mourning Kill (80, 81) show undeformed to isoclinally folded shale, siltstone and thin greywacke beds (<15cm).

Bentonites

Within this unit and parts of the Undeformed Flysch a total of 14 bentonite beds were found, divided among several locations (38,375-377,333). A more thorough search would probably identify more beds. The highest concentration can be seen in the small roadcut of Rt.67 north of Ballston Creek (No. 333, it is located across from a small green road marker sign 67/1503/1164) where 7 bentonites were observed within a stratigraphic thickness of ca. 2.5m (fig. 6). Bentonites are frequent in parts of the Utica shale to the west (Cisne et al. 1982, Delano et al. 1990), but are not described in previously published work from the flysch within the mapping area.

Lithology

Black shale and siltstone dominate along Ballston Creek, and generally in the northern part of the field area, over fewer fine-grained greywacke beds, which nevertheless regularly occur; for instance, in outcrop 261 one 0.5m thick greywacke bed was observed. Along the Mohawk and Lisha Kill greywacke (often crossbedded) dominates over siltstone and shale. The scale of the cross-lamination, defined by the size of packages of conformable uneroded lee beds, is measured in dm rather than cm. Bottom marks are not common. One underside of a shale bed (7) showed one-dimensional, equally distributed, irregular shaped hills (diameter < 1cm), which are interpreted as being biogenic and probably resulting from burrowing. Erosional surfaces and the sense of curvature of the cross-lamination provide younging information.

Figure 6 Three yellow-brown unlithified bentonite beds (top, center, bottom) in gently dipping shale [333]. Blue pencil is ca. 14 cm.

In the vicinity of Lock 7 the greywackes frequently show crossbedding, convolute laminations and dish structures (fig. 7), indicative of unit C of the Bouma sequence (best observed at 12).

The only outcrop of this unit between Ballston Creek and the Mohawk River, at Elnora Creek (331), shows dominantly thin bedded greywacke (< 5cm) turbidites with only minor interbedded shale and occasional thick beds (< 50cm).

The western boundary to the Undeformed Flysch

The placement of the boundary to the western Undeformed Flysch is based on the change of the mesoscale outcrop structure between these units and the occurrence of first, stronger, constrictive deformation. This is obvious in the southern part of the map area along the Mohawk River. Close to the lithological contact within the Undeformed Flysch, very thin striated calcite sheets in a bentonite bed indicate utilization of the bentonite as a shear surface. The first stronger deformation is recorded 300m southeast of this locality. The gently west-dipping black shale turns into a 5-10 meter-wide zone of faulting and disturbance. East of this fault zone, rather steeply east dipping (ca. 40°) brown siltstone and thin bedded greywacke was juxtaposed with the black shale. This fault may be traced across the Mohawk to outcrop 9. Here horizontal black shale beds grade over a distance of about 10m into an incipient shale/siltstone melange having a narrowly spaced set of conjugate fractures and scaly cleavage. From west to east bedding planes change from essentially horizontal to nearly vertical without an actual hinge evident and then to moderate east dips. A penetrative, steeply-dipping cleavage cuts the siltstone perhaps

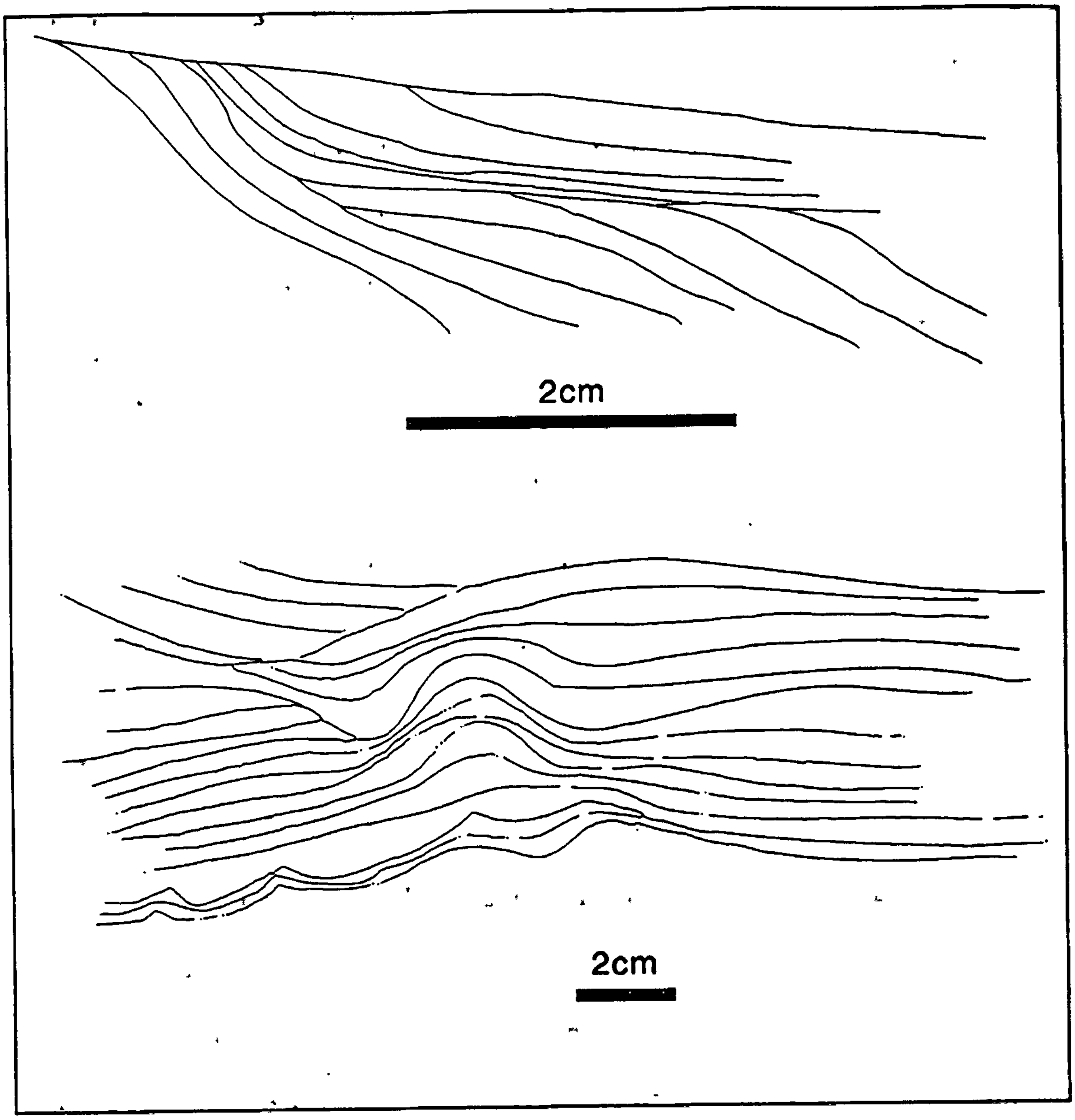


Figure 7 Cross-laminations (top) and cross-laminations overprinted by pore-water escape structures (bottom) in fine-grained greywackes were drawn as observed in outcrop (12).

together with another nearly bedding-parallel cleavage, into small elongate rhombohedra and connects in places to other foliations to produce an anastomosing pattern. The small apparent offset of the rhombohedra indicate local maximum shortening in an east-west direction with a west-down component (fig. 8). The western limit of this zone is not exposed.

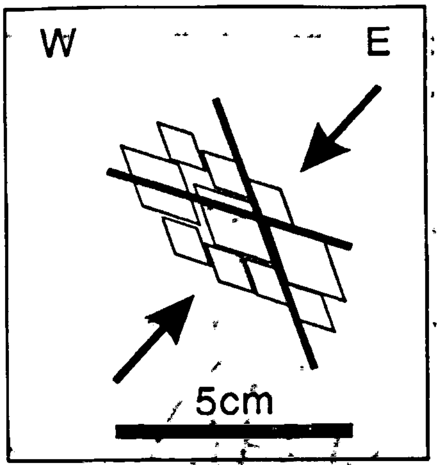


Figure 8 Idealized sketch of rhombohedra at outcrop 9 and interpretation.

In the north near Ballston Creek, the boundary to the west to the undeformed, flatlying shales and greywackes is ill-defined. It is mainly characterized by the change to compact horizontal beds from fairly gently and varied dipping, occasionally cleaved, shale.

Structure

The thin bedded greywackes and siltstones, further to the southeast, towards Lock 7, along the northern shore of the Mohawk (15), show more local zones of disruption and inclined isoclinal folding having small wavelengths (0.1m to 5m) associated with faults. In the vicinity of Lock 7 thin greywackes, with or without interbedded siltstone and shale, have in general steep to vertical attitudes and are isoclinally folded, as recurring changes between normal and overturned bedding show. The best example for a fold having a larger wavelength (> 10m) may be found in a tributary south of Lock 7 (7). Here initially steeply east-dipping east-younging strata turn to the west into vertical west younging strata which is best explained by an tight anticline (fig. 9). The hinge region is not exposed but its existence is confirmed by a recognizable rotation of bedding planes to shallower attitudes towards it.

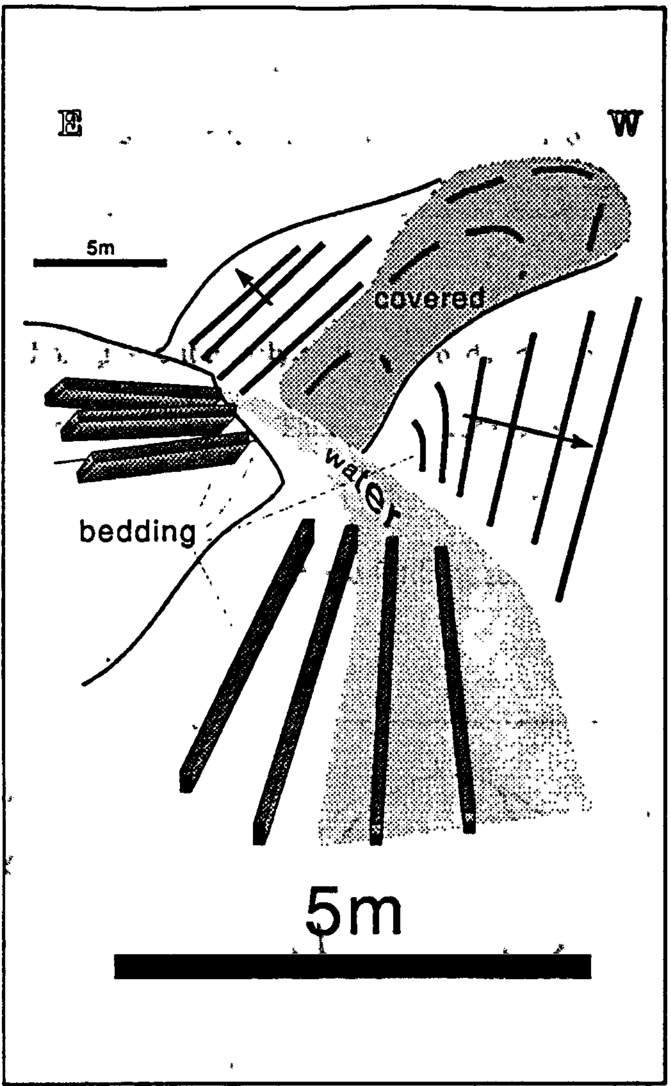


Figure 9 Idealized sketch of field relations at outcrop 7. Bedding and younging (arrows) indicate large wavelength fold.

In general, small wavelength folds are fairly frequent. Hinge lines are close to horizontal. A sample of the hinge of a siltstone fold shows striations on bedding planes perpendicular to the hinge line, demonstrating folding by flexural slip. Faults can be found in nearly every outcrop either as discrete discontinuities between bedded packages or as broader incipient melange zones. Bosworth (1984*b*) described and illustrated the field relations at the Lock 7 Powerhouse, where a steeply east-dipping meter-wide shear zone is associated with narrow horizontal shear zones, phacoidal cleavage, folded fissility and displaced fold limbs. Another broad zone of incipient melange at the southern limit of outcrop 12 shows fairly abrupt boundaries to the surrounding greywackes and the cannibalization of a meter long slab of greywacke which is now enclosed as a block by a phacoidally cleaved shale-siltstone matrix. Possible rotational complexities in near the Lock 7 powerhouse are indicated by abnormally striking and west dipping strata a short distance to the north (11). There also a thin (3m) incipient melange was observed, from which a rhombohedral greywacke block was sampled and cut. It shows striated surfaces and flattening accommodated by conjugate sets of normal faults.

Along Lisha Kill (3) the same lithologies, but mostly in thinner beds (< 5cm), are more strongly cleaved and dip more shallowly to the east. The minor interbedded shales are striated and frequent faults crosscut the tightly folded strata. The irregular cleavage being subparallel to bedding results from disruption by intensive folding, sets of small displacement faults, and a rhombohedral conjugate cleavage. In one case the hinge area of an intact disrupted fold with an essentially horizontal hinge line and axial plane is preserved (fig. 11). The interlimb angle, open to the east, is about 40° and the hinge line strikes north-south dipping slightly to the south (fig. 10). There is a noticeably higher degree of deformation in the Lisha Kill outcrop than in those around Lock 7 at the Mohawk. The Lisha Kill outcrop projects along strike east of Lock 7.

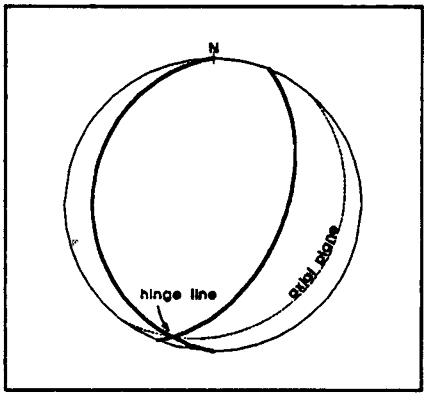


Figure 10 Traces of bedding and axial plane for an individual fold observed at Lisha Kill (3).

The principal structural elements in the series of outcrops along the Mohawk River and Lisha Kill, containing generally bedded, not intensively disrupted strata, with occasional faults or zones of incipient melange, are also recognized in the northern part of the field area.

Figure 11 Horizontal fold hinge in thickest greywackes at Lisha Kill [3].

Elnora Creek (331) offers the only outcrop between the Mohawk River and Ballston Creek. There strata dip gently and are unfolded. At the eastern part of the outcrop a small ca. 40° west-dipping discrete thrust displaces a thick marker bed by ca. 20cm.

Along Ballston Creek, bedded shale and siltstone are locally folded and faulted and in general are only gently dipping. Localized zones of higher strain are indicated by severe deformation at two outcrops (39, 263). Off Ruhle Road in a small quarry (39) the attitude of bedding is characterized by large variations and the black shales are heavily cleaved by curved planes of preferred fracturing. Loose shale blocks are often ellipsoidally shaped and part along curved surface-parallel planes. One horizontal north-south striking hinge line was observed in a tight fold having a horizontal axial plane (not preserved). The stereographic projection of attitudes of representative bedding planes clearly shows rotation about a common axis which is subhorizontal and strikes about 005° (fig. 12).

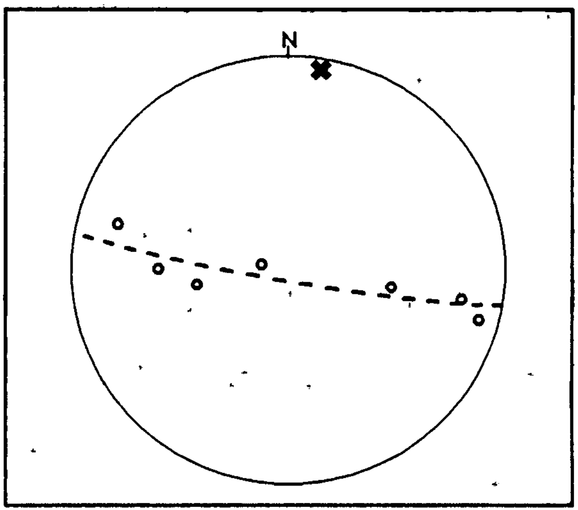


Figure 12 Large variation in poles to bedding describes rotation about single axis (39).

400m westwards a dirt road (263) exposes folded and cleaved shale in a road cut (fig. 13). Loose chips produced by the strong irregular cleavage cover substantial parts of the outcrop. The visible parts give the impression of tight folds with gently east-dipping axial planes. The folds seem to be decoupled from underlying horizontal beds.

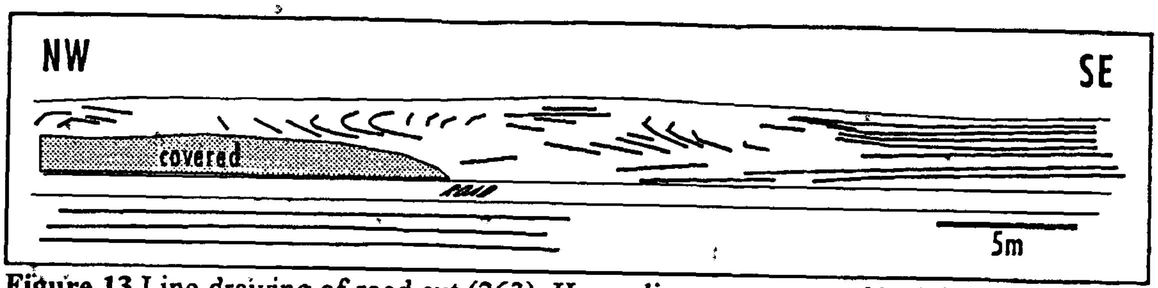


Figure 13 Line drawing of road cut (263). Heavy lines are traces of bedding. Loose shale chips cover substantial parts.

Bedded strata in the continuation of this outcrop in a road-parallel tributary stream indicate gentle dips for the boundaries of the deformed zone.

To the south (262) an open syncline with a wavelength of about 50m in one of the rare thick greywacke beds has an essentially vertical nearly north-south striking axial plane and a horizontal hinge line (fig. 14). Tighter folding in the same outcrop is indicated by isolated vertical 170° striking strata.

To the east towards Round Lake strata are flat lying to gently dipping (<20°). No obvious increase in deformation to the east along Ballston Creek is recorded west of Round Lake. East of Round Lake (197, 49, 196, 254) lithologies, dips and degree of disruption change. Thin greywackes outweigh shale and show restricted zones of heavy, curving cleavage, in which bedding, where preserved, occasionally shows tight to isoclinal folding. Striated shale chips with polished-appearing cleavage surfaces indicate shearing. Dips vary around 40°E and strike averages 020° (fig. 15).

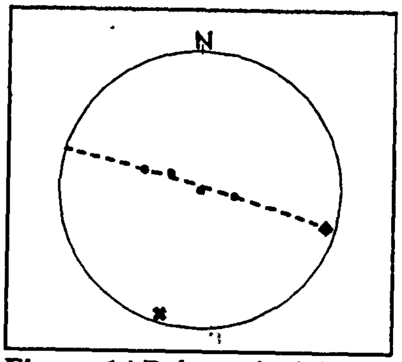


Figure 14 Poles to bedding in open syncline (262).

The characteristics of this lithostructural unit - folding and faulting of bedded flysch are recognised north of Round Lake as well. Tight folds and steeply inclined bedding of siltstone and thin greywacke three miles east of Ballston Spa, visible in a roadcut and along Mourning Kill (83, Saratoga Springs Q.), indicate shortening at least to the longitude of this outcrop. Near the north rim of the Round Lake Quadrangle along East Line Road (303), the steep attitude of 015°/40°E of bedding in siltstone suggests continuity of this deformed belt to the south along strike. Ruedemann mentions in his report of the mapping of Saratoga Springs and vicinity the "steep eastward dip of the Snake Hill beds, which rapidly decreases as one goes east, the part of the Snake Hill belt between Ballston Spa and the lake being but little disturbed by crumbling" (Cushing and Ruedemann 1914, p.105). Without giving more details on the location of deformation, he considers this evidence for the thrust nature of the contact between his Snake Hill shale and Canajoharie shale.

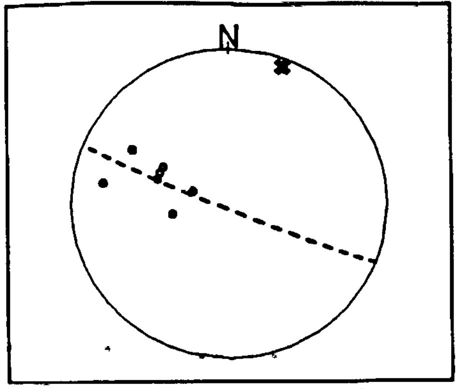


Figure 15 Steeper and more varying dips of bedding (poles plotted) (196).

Further to the east at Saratoga Lake (48,85) grey siltstone and thin, often crossbedded greywacke (<0.1m) are locally disrupted, folded and veined. The rotation of essentially flatlying strata into moderately east dipping attitudes (48) is interpreted as folding about an east dipping axial plane with a 025° trending horizontal hinge line (fig. 16). This is suggested by slaty cleavage having an attitude 020°/20°E observed 500m to the south (85).

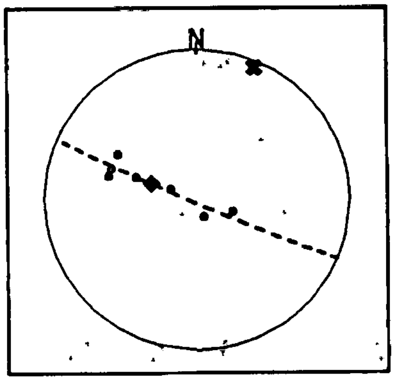


Figure 16 Hinge line and axial plane of tight antiform (48)

There the slaty cleavage was observed in fairly flatlying strata; but more frequently the partly disrupted strata dip considerably (40°-60°) to the east.

The Black Shale occurrence

A distinctly different lithology is exposed in the large roadcut to the east (380) where the Northway I-87 climbs down into the broad valley of Drummond Creek. Fissile pitch-black shale with minor siltstone interbeds is essentially flat lying and undeformed. The fact that west of this black shale tight folds and steep east dips are recorded and that there seems to be a lithological jump from grey-brown siltstones and thin greywackes to black shale suggests a fault contact between the black shale and underlying siltstones. The possibly allochthonous nature of the black shale is consistent with a tentative correlation of the siltstone and thin greywackes with the Frankfort Formation and the fissile black shales with the mostly older Utica Formation. The assignment to the Frankfort is justified by the observed transition from thick massive greywacke beds near the Mohawk to apparently underlying greywackes with finer grain sizes and thinner beds to the north along Ballston Lake and Mourning Kill. Fissile, black shale is typical for the Utica as it crops out in the central Mohawk Valley (Fisher 1980). Also the sequence of deposition during progressive thrust-loading, which is observed at any point of the former carbonate platform and in other passive margin-volcanic arc collision zones (Rowley and Kidd 1981), places shale under greywacke. A possible transport of the black shale from the east would accentuate the age difference as it would juxtapose even older shale with the greywackes.

Two principally different structures can explain the juxtaposition of flatlying black shale and deformed siltstones (fig. 17), a ramp-flat thrust geometry or a normal fault cutting a thrust. The flatlying black shale could be situated above the flat part of a ramp-flat thrust which brought up the shale from under the siltstones and crops out now near the deformed siltstones. Or, the flatlying black shale could represent essentially in-situ black shale from under a thrust which was preserved to the west in a, relative to the occurrence of black shale, down-dropped block. Besides the normal fault the difference between the these two possibilities is that that in the ramp-flat case the black shale is transported and the siltstone is in place whereas in the normal fault case the black shale is in place and the siltstone transported.

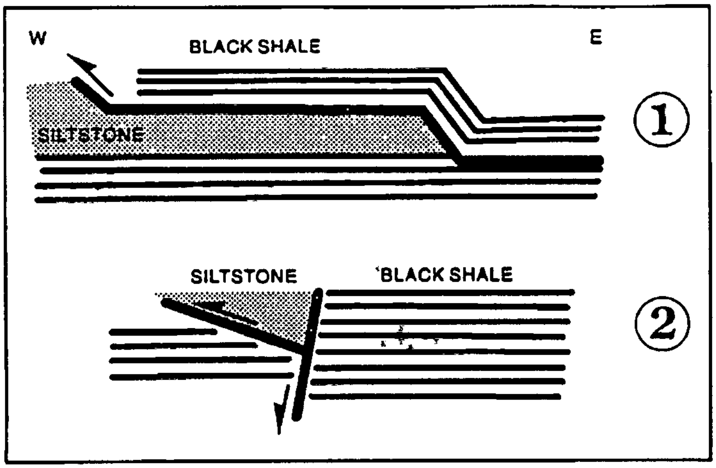


Figure 17 A ramp-flat thrust geometry or a normal fault can explain the occurrence of flatlying black shale.

The ramp-flat explanation is preferred because it is simpler and because no extensional structures have been observed.

<u>The eastern boundary to the Eastern Exotic Melange</u>

East of Lisha Kill, which displays the easternmost outcrop in the south, a large gap in outcrop (ca. 5km across strike) caused by a deep bedrock valley which is now filled with glacial sediments (Dineen and Hanson 1983) separates this belt from the next structural belt.

East of Round Lake the boundary to the east with the Western Exotic Melange is defined by the change from dominantly bedded rocks to a melange-type fabric with phacoidal cleavage enclosing isolated intact blocks. By projecting the closest outcrops from both units (49, 196, 254 to 44, 50, 197) the width of this boundary is estimated to be fairly narrow, probably less than 200m and in places (197) less than 50m. East of Saratoga Lake outcrops show melange-type deformation with scaly cleavage and block-in-matrix textures often without recognisable bedding. The differences in structure define the eastern boundary of the described lithostructural unit. It is placed along the trace of the long recognised Snake-Hill thrust (Cushing and Ruedemann 1914, Bosworth et al. 1988) exposed at Snake Hill where a greywacke melange structurally overlies deformed thicker greywackes (<1m), here untypically rich in larger fossils (<3cm), mostly brachiopod shells and crinoid parts. The distinct change in lithology and structure from west to east shore indicates that substantial melanges might well occur west of Snake Hill under Saratoga Lake. Therefore the width and placement of the boundary is not well constrained within Saratoga Lake.

A spaced (5-20cm), in places calcite-filled, vertical jointing in various densities overprints many outcrops in the northern field area and seems to strike preferentially 060°. It affects also undeformed flysch (81).

Summary

A Folded and Faulted Thin Greywacke, Siltstone and Shale unit can be distinguished in the field area. Its western boundary is defined by the change from essentially flatlying strata to folded and faulted strata. This change is well defined and exposed in the south along the Mohawk River, whereas it is less distinct in the north, probably due to worse outcrop. The eastern boundary is defined by the occurrence of thick melange zones, penetrative disruption, and the vanishing importance of bedding as a defining structural element. It is not exposed along the Mohawk River and appears to be of fairly restricted width (50m-500m) in the north. On a smaller scale there are significant heterogeneities within this unit. Along the Mohawk River and south thin bedded greywackes are lithologically dominant to exclusively present, whereas in the north they are replaced by siltstone and shale. Structurally, steep to vertical attitudes and frequent isoclinal folding along the Mohawk contrast with shallow dips and localized deformation in the north.

Graptolites and age

Dicranograptus nicholsoni Hopkinson
Diplograptus (Mesogr.) putillus Hall
Corynoides sp.

Figure 18 Graptolites found at Snake Hill (Cushing and Ruedemann 1914)

Ruedemann (1930) indicates several graptolite localities within this unit (9, 81, 39, 800m ESE 39 now covered, 6, 600m NNW Lock 7, 3). All except the most western one along the Mohawk (9) were assigned by him to his Snake Hill shale. The exception was assigned to his Schenectady beds. Unfortunately Ruedemann (1930) does not specify single outcrop assemblages but gives only bulk lists of species. In other related publications (1901, 1908, 1912 and in Cushing and Ruedemann 1914), in which Ruedemann describes graptolite content of specific localities, the localities concerned are not included. He gives, however, a fossil list from the Snake Hill locality which includes three graptolite species (fig. 18). If his age assignment as Snake Hill shale is correct, then the dark undeformed shale west of this most western locality should be of similar or younger age, because the contact is most likely of thrust nature. Consequently, lithostratigraphic assignment of these dark shales (Utica) would be different from biostratigraphic assignment (younger than Snake Hill). This difference would imply a shift in age for the dark shales from Utica to a younger age or for the overlying thick greywackes from Snake Hill to an older age.

Berry (1963) found, at Snake Hill, graptolites diagnostic of his *Orthograptus truncatus var. intermedius* Zone, which corresponds approximately to Riva's *Corynoides americanus* to *Climacograptus spiniferus* Zones (Berry 1971, Rickard and Fisher 1973, Finney 1986). He also found in the shell-rich beds the trilobite *Cryptolithus tesselatus*, which points to a Trentonian age (Ruedemann 1930) and indicates a correlation with the lower part of the Sherman Fall Limestone, the Shoreham Limestone (Berry 1963). This is consistent with an age younger than the undebated *Nemagraptus gracilis* Zone at the older end of the Medial Ordovician.

The eastern boundary and Ruedemann's line of "Intense Taconic Folding"

Ruedemann places his line of "Intense Taconic Folding" at about the same position as the eastern boundary of this lithostructural unit. He does not elaborate much on this line and gives no indication of the process of placement of it (Ruedemann 1930). In the description of his map some sections are illustrated by line drawings of Mather (1843) and Ruedemann (p.139, 140, 142). The sections from the Mohawk shore indicate similar observations to those described above, that is frequent tight folding and faulting. Due to imprecise descriptions of the localities and disappearance of outcrops observed 150 years ago, most sections could not be unquestionably located. One locality described as "two miles from Alexander bridge (Rexford)" with illustrated compressional features may hint at deformation within the Undeformed Flysch. An illustration from the "southwest shore of Saratoga Lake" (p.142) (maybe 85) shows discrete curved faults, described as thrusts.

Correlation with Vollmer's unit of Gently to Isoclinally Folded Flysch

Vollmer (1981) describes a similar unit of gently to isoclinally folded flysch. The streuctural correlation of Vollmer's unit with my Folded and Faulted Thin Greywacke, Siltstone and Shale unit is justified because in both units strata are folded and faulted, but not pervasively disrupted. Small incipient melanges occur in both units and confirm their correlation. A stereographic projection of 141 poles of bedding (Appendix 2 in Vollmer 1981) in Vollmer's area shows, besides moderate to steep dips, also frequent gentle dips and, overall, as many western dips as eastern dips. In my field area gentle dips are common in the Ballston Creek section, but not to the south, and western dips are very rare.

The western boundary of Vollmer's unit seems to be fairly well defined and joins with the western boundary of the unit described here if extrapolated to the north through an area of no outcrop. Its eastern boundary is less well defined by confining outcrops. The eastern boundary is drawn by Vollmer (1981) as swinging from northern to northeastern trends to the north, with the northeastern trend being queried by Vollmer as not supported by field data. The placement of the eastern boundary of the equivalent unit in my field area is not consistent with an extrapolated northeastern trend of the same boundary in Vollmer's area, but suggests more northern trend to connect them.

Western Exotic Melange

The Western Exotic Melange Unit is the westernmost belt in a broad band of complexly deformed flysch, containing locally exotic lithologies, which extends towards the Taconic Frontal Thrust. Characteristic of this band is overall the frequent occurrence of an anastomosing scaly cleavage and the generally minor importance of bedding as a structural element. Useful subdividing characteristics within this broad stripe are the occurrence of exotic, that is non-flysch, lithologies and the occurrence of larger bedded subdomains.

The main criteria for distinguishing between a Western Exotic Melange and an Eastern Exotic Melange is their separation by an extensive bedded greywacke unit. The outcrop situation does not allow for a more sophisticated characterisation of these two melange units, and in fact they appear to be fairly similar. Accordingly, in areas where the defining bedded greywacke unit between is missing, distinguishing these two melange belts is not easily justified, but the distinction is still maintained mainly for the purpose of description, ease of discussion and in view of a desirable map-scale coherence. The same arguments are valid also for areas between which there is a separating bedded greywacke and for which one might stress the definition of a lithostructural unit as based on its lithological and structural appearance and not as based on its surroundings.

Lithology

Lithologically, the whole collection of flysch sediments - shale and turbidites in variable grain sizes - can be found. Shales and siltstones dominate over fine grained greywackes and rare coarser greywackes.

Some (66,44,45,200) of the outcrops (additionally 50,51,57,197,43,199,198,250) grouped into this unit contain exotic blocks composed of massive black chert, sideritic mudstone, green siltstone, pyritiferous micritic dolomitic limestone, red-brown fine grained sandstone (45) or siliceous (?) deep black shale (200), apparently all not directly related to flysch deposition, which has important implications for the geologic history of this area. The best outcrop (66) showing these lithologies is located east of Interstate 87 800m south of exit 9 within the grounds of the construction company K-C-Canary.

Structure

At K-C-Canary (66) the exposed melange contrasts drastically with the described units to the west. Heavily disrupted, phacoidally cleaved dark shale shows frequent fracture surfaces with a glazed appearance, probably a result of orientation of very small grains of phyllosilicate. The shale encloses slabs and lenticular blocks of internally little deformed grey, usually fine-grained greywacke, black chert, red weathering sideritic mudstone and brown weathering bright grey micritic limestone. Thin (<3cm) seams of white-weathering pale green shale are discontinuous and interweaved with dark black

Figure 19 Laminated greywacke block in dark phacoidally cleaved shale. Bright seams are pale green shale. At K-C-Canary, Clifton Park [66].

Figure 20 Part of outcrop at K-C-Canary [66]. White band is gently dipping slickensided quartz-calcite vein dipping gently east.

shales (fig. 19). These pale green shale seams occur spatially concentrated and systematically together with other exotic lithologies. Euhedral pyrite is common, especially in the carbonate and green shale. A strong, narrowly (mm) spaced anastomosing cleavage dominates the structure as a foliation with an attitude of 010°/40°E. A slickensided planar calcite vein (<2cm) strikes approximately north-south and dips about 5° to the east (fig. 20). It crosscuts the anastomosing cleavage, and the striations on it trend 140°. In loose pieces from excavations just to the north, more slickensided veins with a variety of thicknesses and crystal sizes as well as irregular not-slickensided vein-arrays were found. About 20m to the east temporary excavations for a new waterline exposed no more exotic lithologies, but instead compact grey fine grained greywackes and siltstones. They show a transition, from the melange-fabric with its narrowly spaced anastomosing cleavage enclosing phacoids and slabs of precursor material, to a broken appearance with cm-spaced, more planar, not mineralized or striated fractures producing larger, more rectangular-shaped blocks. Bedding is still difficult to recognise due to lack of internal laminations and only subtle changes in lithology, but appears to follow, together with a dominant fracturing foliation, the same general attitude as the phacoidal cleavage in the melange. A 1cm thin yellow-brown, poorly lithified clay bed traceable for 3m seems to be bedding parallel and is interpreted as a bentonite bed. The alternative interpretation as fault gouge is less likely, as no increasing strain towards the clay bed, no lithologic difference across the clay bed, nor any systematic asymmetries of discontinuities inside the clay bed resulting from shear strain, were observed.

These observations from the most important outcrop within the Western Exotic

Melange are supplemented by observations from outcrops along strike. Along Dwaas Kill (44,50,51) outcrops expose mostly well-developed melange, rarely crosscut by planar quartz-calcite veins. The striations on these veins are repeated within dark layers probably composed out of clay minerals and residual opaques in the veins, which can divide the total vein into some, a few mm-thick plates. Outcrop 44, north of Tabor Road, yielded a m-long carbonate-slab. Dips of the melange foliation vary from gentle (50) to steep (51); strikes parallel the regional strike of 020°.

A roadcut at Usher Road (45) shows the singular occurrence of a melange containing exotic blocks in a peculiar resistant matrix composed of a greenish siltstone. Compact green siltstones also comprise some of the exotic blocks; others consist of carbonate and a brown-red micaceous sandstone.

The list of exotic lithologies is further extended by deep black mudstone found as blocks (<1m) in an unusually narrowly cleaved melangy shale matrix at Saratoga Lake (200).

A short distance to the east (199) flysch-only melange separates few and small bedded shale-greywacke sequences in a continuous stream section. Within the melange fabric the regularity of the shape of greywacke blocks as rhombohedra is noteworthy. The contact between bedded material and melange is transitional over a distance of about one meter within the outcrop.

Close to the Mohawk River at Mohawk View along the bike path (57) shales, siltstones and thin bedded greywacke appear heavily cleaved, isoclinally folded and generally bedded, but disrupted. They are grouped into this melange unit, despite the fact that they do not show a classic block-in-matrix fabric, because they contrast so markedly with the well-bedded, outcrop-wide unfolded m-thick greywacke turbidites exposed at a 25m-cliff 1.2km to the east, which belong to the Halfmoon Greywacke Zone.

The western boundary with the Halfmoon Greywacke Zone and its northern equivalent

Contacts of the Western Exotic Melange with the western side of Halfmoon Greywacke Unit, are nowhere exposed and believed to be transitional, as no sharp boundaries between melange and bedded units are observed anywhere in the field area. It is not possible to estimate the width of the transition, because the closest distance between outcrops of the adjacent units is the 1.2km mentioned above. The boundary drawn is "thick-bedded-greywacke-sensitive". It excludes areas without the defining massive, bedded greywacke from the uniform Halfmoon Greywacke Zone and includes them with the heterogenous Melange unit. The same criterion was used to define the boundary between melange and bedded greywacke in the northern part of the field area east of Saratoga Lake, where a lithostructurally equivalent situation is encountered.

Between these northern bedded greywackes (east of Saratoga Lake) and the southern Halfmoon Greywacke Zone, outcrops along Anthony Kill (251, 69, 382, 252, 253, 46) show a break along strike within this belt in that massive, bedded greywackes are absent. Greywacke-rich, relatively coarse flysch-melange dominates this section (fig. 21). It is included within the Western Exotic Melange, although no exotic material was found, partly because the section does not offer specific enough information to justify the

Figure 21 Greywacke block rich melange at Anthony Kill [69]. Hammer for scale.

Figure 22 Banded, slickensided quartz-calcite vein crosscuts phacoidal cleavage which encloses small greywacke block. Anthony Kill [69].

definition of another mappable unit and partly because the outcrop itself may indicate a natural transition towards the main melange belt, including exotic lithologies, to the west. A 250m long railroad cut (69) shows well developed melange fabrics within dominantly siltstone and fine grained greywacke. In places slabby greywacke blocks follow and help emphasize the phacoidal cleavage foliation. It dips to the east and southeast with an average angle of about 40° (fig. 23). Halfway to the west, veining begins and grades towards the west from mm-thin calcite sheets to cm-thick slickensided calcite-quartz planar veins (fig. 22). Slickensided veins dip east at various angles and slickenlines trend between 090° and 150° (fig. 24). Veins thicken slightly towards the west, and also block shape and the type of cleavage changes subtly towards the west from more rhombohedral with ,in places dominant, planar discontinuities to irregular and wavy. The gradients in veining and internal fabric may hint at affinities with the exotic melange along Dwaas

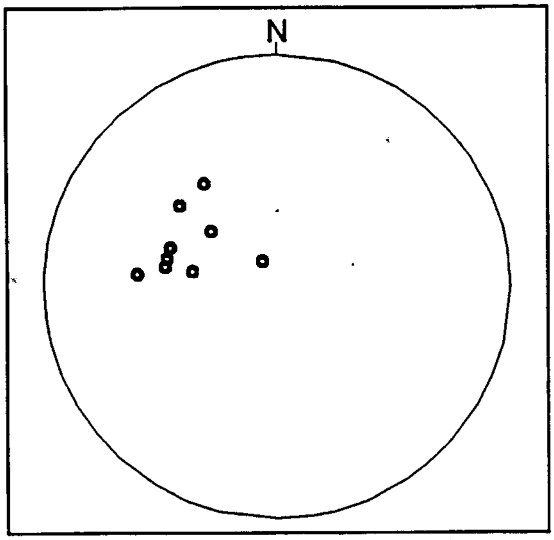


Figure 23 Poles to phacoidal cleavage, n=9, Anthony Kill (69).

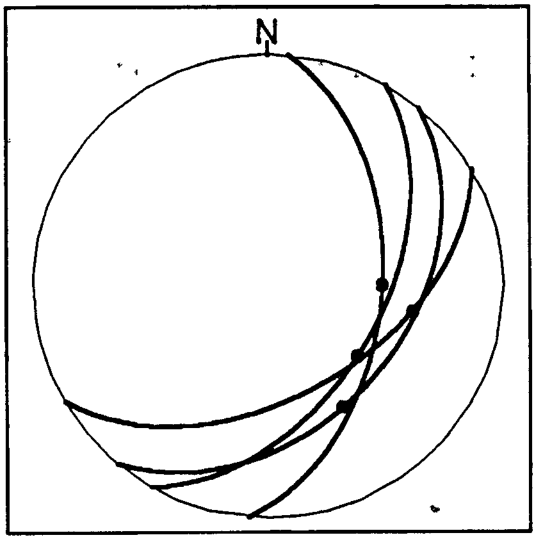


Figure 24 Traces of slickensided veins with lineation, n=4, Anthony Kill (69).

Kill (44, 50, 51) and at K-C-Canary (66), which is veined and shows phacoidal cleavage and irregular blocks.

Graptolites and age

Ruedemann indicates seven graptolite localities (44, east 69, east 46, three at 199, 198) within the Western Exotic Melange. All except one (198) were assigned to his Snake Hill beds. 198 is indicated on his map as belonging to his Normans Kill shale. Again it was not possible to identify graptolite contents of single outcrops using Ruedemann's publications.

Correlation with Vollmer's units

Vollmer (1981) divides his Taconic melange into three units, a western belt, an eastern belt and the Normanskill melange. The western belt corresponds to both the Western Exotic Melange and the Eastern Exotic Melange of my mapping, as south of Albany there is no separating massive, bedded greywacke within Vollmer's western belt. Vollmer describes melange fabrics which were also recognised within the Western Exotic Melange and found exotic lithologies, namely black chert, as "blocks and sheets within the Taconic melange" (Vollmer 1981, plate 1A).

The area described in older publications

The state map (Fisher et al. 1970) includes most of the area of the Western Exotic Melange into its Canajoharie Shale. As all of the field area to the west is shown as Canajoharie Shale, none of the distinctions in lithology and structure made above are indicated, most importantly the change from bedded flysch to heavily disrupted block-in-matrix melange. East of Saratoga Lake Mt. Merino Fm. is depicted, but no characteristic massive, black chert was found there. Further north, and also east of Saratoga Lake, Ruedemann (in Cushing and Ruedemann 1914) indicates, in places, extensive outcrops of white weathering, ridge forming cherty beds. These may indicate large exotic blocks or slivers within the melange as it continues north along strike.

The NYS geological highway map (1990) shows all of the field area from the Western Exotic Melange to the west as Snake Hill shale, including the mentioned area east of Saratoga Lake.

Summary

From these observations it is clear that there is an extensive melange unit 11km across strike to the west of the traditionally defined boundary of the Taconic Allochthon (Logan's line). All melange fabrics are fully developed and the apparent degree of disruption equivalent to the degree of disruption observed in melanges further east. Also, the melange contains in places lithologies that are not related to flysch deposition.

Folded Thick Bedded Greywacke (Halfmoon Greywacke Zone)

The Halfmoon Greywacke Zone (HGZ) is characterised by the striking contrast of its lithology and structure to its surroundings. Well bedded greywacke turbidites can have thicknesses in the dm- and m-scale (fig. 25) and are separated only by thin interbedded shales (< 5cm). This unit is well exposed along the Mohawk River (395, 24, 25, 26, 61, 62 ,63, 64, 28, 220, 221, 222, 223, 189, 28.5, 178, 182, 354) and south of it (18, 19, 20, 21, 22, 23, 218, 219). North of the river, only one large (30) and three small outcrops (31, 193, 272) help in estimating the spatial extent of this unit.

Lithology

Bottom marks such as flute casts or load casts, normal grading, large wavelength/low amplitude crossbedding (fig. 26) and persistent constancy in bed thickness are commonly observed sedimentary features of the turbidite beds. Grain size is fine to medium, including the m-thick beds. In the area around the ridge between Dunsbach Ferry Rd. and Rt. 9 and west of the I-87 bridge across the Mohawk meter thick beds can be found, whereas east of the bridge in the Colonie Park area (28, 220, 221) mostly cm thick beds are seen (fig. 27). An exception is the coarse (grain size < 3mm) and very immature appearing greywacke which forms the bedrock ridge just east of I-87 and north of the Mohawk (61, 62, 63). Channeling is restricted to erosional bases and is of small cross-sectional width (< 0.5m), where observed. Convolute bedding, seen ot one locality (fig. 28), indicates rare slumping.

Figure 25 Interbedded greywackes and shale gently east dipping [18]. Red cord plus compass is ca. 60 cm. and vertical.

Figure 26 Climbing ripples define mild cross-bedding. Foresets are thin greywackes [20].

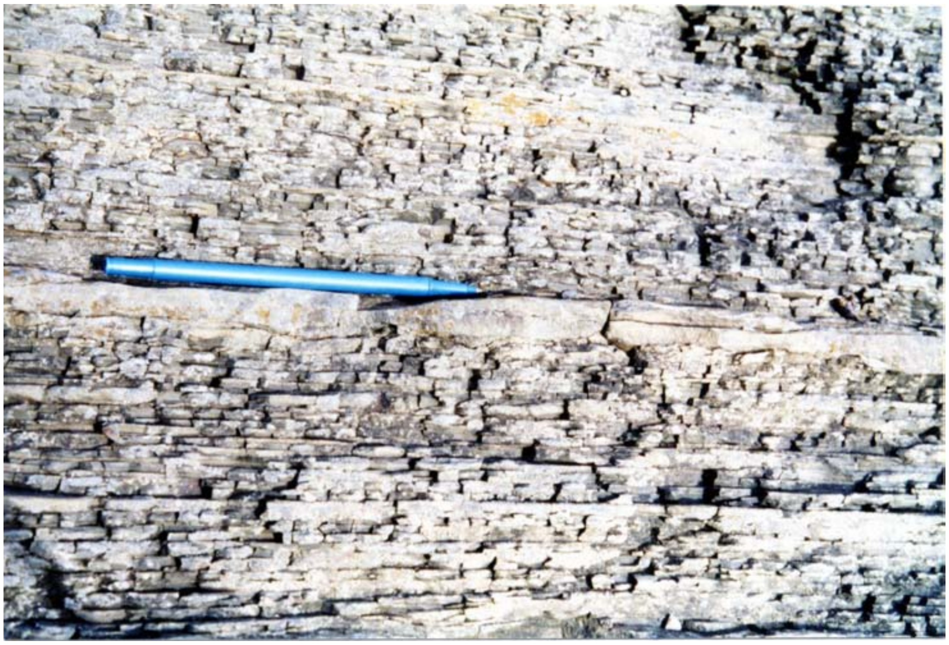


Figure 27 Multitude of cm-thick turbidite individuals without shale interbeds [220].

Figure 28 Slumping of thin turbidites [221].

Structure

In the southern better exposed area outcrops delineate three NE-SW striking units with characteristic attitudes of bedding (see map in map pocket). Moderately SE dipping beds are followed to the SE by vertical beds. They exhibit the same general strike and are in turn juxtaposed further east with a diffuse zone possessing a probably complicated, not resolvable structure expressed in various attitudes of bedding, including strikes nearly perpendicular to the general strike, and locally observed faulting (28.5).

Stereographic projection of poles to bedding planes within the western, moderately dipping, unit shows clustering centered at about 040°/45°SE as the attitude of the average plane, the pole of which is indicated on fig. 29. Three planes do not follow this trend. One strikes nearly perpendicular to the general strike (155°/20°NE at 25), one is nearly horizontal (222), and one has an attitude of 085°/40°S (28.5). The position of the nearly horizontal beds closest to the adjoining belt of vertical beds is one of three arguments for suggesting a tight regional synclinal synform. The other two arguments are discussed later. For the other two unusual orientations of bedding planes (25, 28.5 west) no straightforward interpretation is available. The fairly gentle dips allow for substantial changes in strike without large amounts of effective rotation. Therefore the unusual

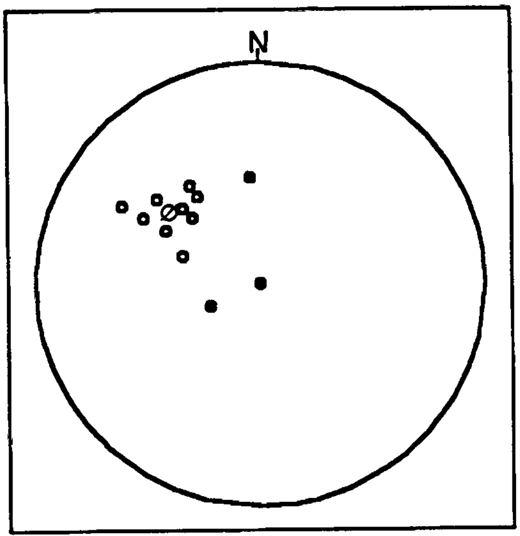


Figure 29 Clustering of poles to bedding at about 040°/45°E (ø) and three unusual attitudes (•).

orientations may be seen as local disturbances within the overall structure of the regional syncline. This is especially true for the southern locality (25) where the unusual attitude is surrounded to the west, north and east by more common attitudes. This arrangement does not leave appreciable space for regionally important changes in the structural interpretation, for the moderately SE dipping unit, as the western limb of a regional syncline. Therefore the existence of folds of a higher order with an axial plane at a high angle to the axial plane of the main syncline is suggested as the least complicated modification. The outcrop situation is different for the northern locality (28.5). Here the unusually W-E-striking beds occur isolated, with the surrounding structure less well constrained. This allows for a variety of scenarios resulting in the observed outcrop structure. Locally important or regionally important implications may be distinguished. Locally, the unusual attitude may indicate higher order folds or rotation due to nearby (early) small-scale faulting. Regionally, the unusual attitude may indicate a general bend in the structural trend towards the north or may be related to its position near the boundary to the easternmost structural unit within the HGZ.

A structural unit consisting of vertical beds is mainly defined by outcrops (19, 20, 21) at a bedrock ridge NE of Dunsbach Ferry Road. 1.5km to the NE (219) vertical beds are correlated due to their position along strike. Further to the NE, horizontal, cleaved siltstone (189) and only gently dipping greywackes (28.5) delimit the vertical unit. Bottom marks (20), grading (20) and crossbedding (19) clearly demonstrate younging to the NW. In connection with the SE younging directions of the gently dipping unit (26, 220, 221) the younging directions are the second argument for the existence of a regional tight synclinal synform. Thirdly, a weak slaty cleavage, observed in one outcrop (20), dips about 60° to the SE, which is, if accepted as being parallel to the fold axial plane and a result of folding, in accordance with the already inferred fold geometry with a gently dipping western limb, a vertical eastern limb and an about 040° trending hinge line.

The few outcrops east of the vertical unit (23, 178, 182, 354, 28.5 east) are grouped into one unit mainly because of their lack of mutual resolvable relations and also because of their higher degree of outcrop scale deformation. Both criteria indicate a more complex structure in this unit. Lack of exposure prohibits a reasonable guess of the structure's detailed nature. The higher qualitative degree of mesoscale deformation compared to the units to the west can be observed best at a drowned quarry at the southern end of the Rt. 9 Mohawk River bridge (28.5). The mining cut into the south dipping, massive, well bedded greywackes, but left the eastern wall unprocessed, where the greywacke becomes broken with continuous bedding planes only in the scale of meters. The change from undeformed to broken greywacke appears to be abrupt at a width of less than 3m. The actual contact is covered with debris and vegetation. The strike of the contact as indicated on the map (in map pocket) is taken to be parallel to the strike of the eastern quarry wall, being about 030°.

Quickly steepening dips and changing strikes in well-bedded greywackes close to the eastern boundary of the HGZ (354, 182) distinguish these outcrops from the western units within the HGZ, which have outcrop-wide uniform attitudes, and indicate a higher degree of deformation to the east.

Cleaved, horizontal dark siltstone and shale (189) close to the boundary of the unit of gently inclined beds are unusual in their lithology, attitude and irregularly cleaved structure. They are not included in the gently inclined unit, because of these unusual properties. They may represent part of the fold hinge of the regional syncline to the south which would explain the attitude and cleavage. This model is not preferred, because the expected vertical, resistant greywacke beds to the east were not observed nor do the closest outcrops (28.5, 354, mentioned above) suggest them. Instead, the location near the boundary is taken to indicate a fault nature of this boundary, which also explains the unusual properties as resulting from juxtaposition and higher strain.

The isolated occurrence of a 100° striking, vertical bed (23) is grouped into this unit as well, but not very helpful for its further interpretation except in suggesting more complexity due to its strike at an high angle to the general strike.

Summary

Apart from all the complications, a threefold division in the southern HGZ can be clearly recognised. A broad western belt of gently inclined strata combines with a narrow belt of vertical strata to define a tight regional syncline, which was juxtaposed by faulting to an eastern belt which itself is characterised by frequent folding and faulting. This scenario is only the simplest picture that is compatible with the outlined field relations. A possible modification, for example, is to treat the broad gently dipping section as an essentially isoclinal fold-pair. One overturned section with an inferred slightly steeper dip would strongly suggest such a pair. Beds in the conjugate fracture outcrop (64) dip steeper and may be interpreted to be overturned. Also, a number faults within the generally well-bedded and uncleaved western limb are expected to have accommodated strain in addition to the folding. Perhaps the coarsening towards the the 400ft greywacke ridge along the

Mohawk (61,62) was originally more gradational and was modified and accentuated by faulting and shortening. These assumed faults probably have not caused significant displacements in the map scale, as they neither express themselves in outcrops nor separate distinctive structural domains.

The postulated fault which juxtaposes the western fold with an eastern, more strongly deformed terrane, cuts the fold hinge. Therefore, the southern HGZ was deformed in at least two stages. This little history of deformational stages supports the notion that reconstructing and comparing paleostresses here is difficult (see attempt in appendix 2).

The eastern boundary with the Eastern Exotic Melange

The eastern boundary of the HGZ was not observed. It is fairly well defined along the Mohawk River, less well defined to the south, and interpretable in the north. It seems that the width of the transition between bedded material and melange is broader in the east than in the west. This estimate assumes that the more deformed eastern belt in the southern HGZ belongs to the transition. It is alternatively possible that there is still a fairly sharp contact, with a width of a few meters, if the more deformed zone is not directly related to the contact-creating process. This could only be determined at an exposed contact. Confining outcrops at the western and eastern shore of the Mohawk at Crescent dam (354, 183) let it appear possible that such a contact may be observed on the island, which connects the western and eastern parts of the dam. Unfortunately, it is not accessible without a boat and was not visited.

The northern HGZ

The northern HGZ is only very sparsely exposed (30,31, 193, 272). Lithologies are generally similar with a tendency to be more immature. This is indicated by higher feldspar and calcite contents (31, 193), coarser grainsize (31), larger and less regular bed thicknesses (30), and the occurrence of large, cm-sized pale green shale chips (rip-up clasts) at bed bases (30).

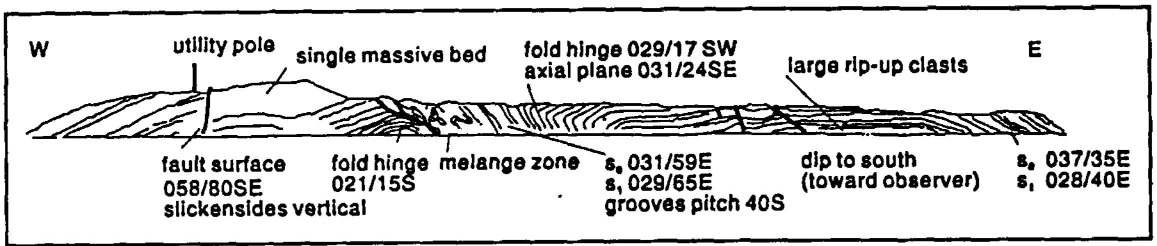


Figure 30 Roadcut of Rt. 146 (30). Steep limb of major fold east of melange zone is overturned (modified after Kidd, 1992, pers. communication).

Lack of outcrop prevents any determination of regional structure. Mesoscale structural information is provided by a large roadcut (200m) of Rt.146, Clifton Park (30). The following information and the original outcrop sketch (fig. 30) is mostly provided by Kidd (1992, pers. communication). The structure is characterized by generally gentle dips, small faults and a melange zone with disrupted bedding. The central melange zone abuts to the west fairly sharply against a mild antiformal fold and is followed to the east transitionally by the overturned beds of

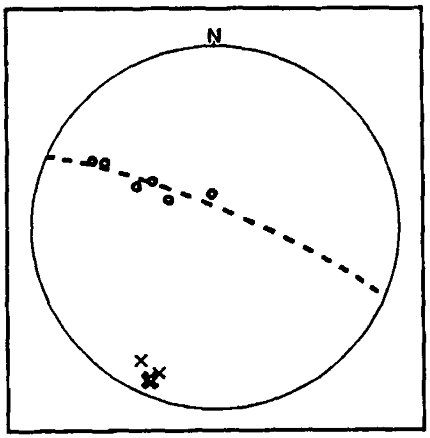


Figure 31 Poles to foliations (bedding, cleavage, axial plane) = •, fold hinges = x, pole of common great circle = **x**.

the steep limb of an inclined fold with an gently east dipping axial plane. At the west end of the outcrop beds dip to the west, the only west dips in the HGZ observed and one of the very few in the total mapping area. The melange zone is the most interesting local structural element, as similar occurrences were not observed in the south. Its tectonic origin as a fault zone is indicated by its fairly sharp, truncating contact to the west and its involvement in the inclined fold to the east. The stereographic projection (fig. 31) of all measured foliations except the 058° striking, steeply dipping western fault exhibiting vertical slickensides shows that they can be produced by rotation about a common axis with an attitude of 025°/10°, which nearly coincides with the attitudes of the hinges of the two measured folds.

The melange zone, the quickly-changing attitudes including western dips, and the generally complex structure exposed at this roadcut (30) would favour a tentative correlation with the eastern more deformed structural unit of the southern HGZ. The position of this outcrop, however, does not project along strike into this unit. In other words, the more deformed unit seems to follow more the eastern boundary of the HGZ than the general strike of 040° within the unit. This conclusion indicates that at least parts, if not all of the deformation seen in the eastern part and in this roadcut is related to the "creation" of the eastern boundary of the HGZ with the Eastern Exotic Melange. Also, the attitude of the common rotation axis is parallel to the general strike outside the HGZ rather than lying within in the axial plane of the southern regional fold inside the HGZ. Therefore the attitude of the common rotation axis supports furthermore an origin of deformation related to "outside"-processes rather than early folding within the HGZ. (Then, the question remains, why is the boundary itself not parallel to the general strike?).

Graptolites and age

On the accompanying map the position of three graptolite localities is shown. The two eastern localities are given by Ruedemann (1930), the western one is discussed by Berry (1962, 1977) and Rickard and Fisher (1973). Ruedemann (1930) includes the two localities in his Normans Kill shale, for which he gives a bulk list of graptolites (p. 99-101). For the eastern locality, the drowned quarry at the Rt.9 bridge (28.5), Ruedemann (1912, p. 31) gives a graptolite list in an earlier publication (fig. 32). Rickard and Fisher (1973) correlate this assemblage with the late *Diplograptus multidens* or *Corynoides americanus* zone of Riva (1974). Riva (1974) included *Climacograptus bicornis* in the *Nemagraptus gracilis* zone and recognized a directly following *Diplograptus multidens* zone. For Finney (1986) it is not necessary to retain a *Diplograptus multidens* zone, because its name-giving and defining graptolite is not common outside its type area. He shows that it is nearly time-equivalent to a *Climacograptus bicornis* (sub)zone, which extends a little lower into the *Nemagraptus gracilis* (sub)zone than the *Diplograptus multidens* zone. *C. bicornis* is restricted to its zone (Finney 1986). Therefore its occurrence in outcrop 28.5 excludes younger ages.

Corynoides calicularis Nicholson
Cf. *Azygograptus ? simplex* Ruedemann
Diplograptus putillus Hall
Climacograptus bicornis Hall
Diplograptus cf. *angustifolius* Hall
Leptograptus annectans Walcott (Narrow form)

Figure 32 List of graptolites at outcrop 28.5 (from Ruedemann 1912, p.31)

Most graptolites in Ruedemann's (1930) bulk list were found near Glenmont, south of Albany, and he specifies in the list for each species the localities of the six other principal localities where the fossil was found or "etc.", meaning the remaining localities indicated on his map. As the other, more western of Ruedemann localities belongs to his "etc."-localities, it is only possible to state that a uncertain number of the 14 graptolite species, which these localities furnished, were found there, having at least the certainty that he did not find any other. Then, it may be helpful to see if all of these graptolites belong to one or two predefined assemblages, recognized by more recent work.

Orthograptus truncatus truncatus (Lapworth)
Orthograptus sp. (of Elles&Wood Group II)
Pseudoclimacograptus scharenbergi (Lapworth)
Climacograptus sp.

Figure 33 List of graptolites south 61 (Berry 1977)

The western locality (south of 61), referred to in the literature as "an old quarry near the abandoned Erie Canal 6 miles N40°W from Troy" was examined by Berry (1962, 1977) and Rickard and Fischer (1973). Berry (1977) depicts and names 4 graptolites from this outcrop (fig. 33). *Orthograptus* sp. (of Elles and Wood Group II) and *Pseudoclimacograptus scharenbergi* (Lapworth) are the most numerous species. Berry (1977) assigns this assemblage to his *Orthograptus truncatus var. intermedius* Zone, which corresponds approximately to Riva's *Corynoides americanus* to *Climacograptus spiniferus* zones (Berry 1971, Rickard and Fisher 1973, Finney 1986). Berry (1977) admits, however, that several common graptolites of these zones are missing. Stratigraphically, he assigns the greywackes in the outcrop to the Austin Glen Member of the Normanskill Formation (Berry 1962, 1977). Rickard and Fisher (1973) also found graptolites at this locality, but do not report identifying them. They claim that shallow-water criteria are abundant in the outcrop and assign the greywackes to the younger Schenectady Formation. The massive, immature appearance of the unusually coarse-grained greywackes at the 400ft ridge northeast of the I-87 bridge, in which the old quarry concerned is located, is, I found, an exception. In the majority of nearby outcrops, deep-water turbidite origin explains best the observed sedimentary features. The coarser grainsize and massive beds with less distinct undersides are preferrably interpreted as properties of more proximal turbidite/slump-deposits.

Riva (1983, pers. communication to Kidd) recognized at outcrop 178 his *Nemagraptus gracilis* fauna, which is older than his *Diplograptus multidens* fauna, but contains *Climacograptus bicornis* (Riva 1974, Finney 1986).

It is reasonable to view this unit as a lithostructural unit with a sedimentary age or age range somewhere between the *Diplograptus multidens* or *Nemagraptus gracilis* and *Climacograptus spiniferus* zones of Riva (1974). This includes the whole Medial Ordovician, either due to prolonged deposition or, more likely, mistakes in recognition, interpretation and correlation. The "young" orthograptide (Berry 1977) and the occurrence of "old" *C. bicornis* and the *N. gracilis* fauna (Riva 1974) indicate an age range centered about Finney's (1986) *C. bicornis* (sub)zone but with a poorly constrained lower and upper limit. These ages and the lithology is consistent with an assignment to the Austin Glen Formation.

Similar units described in older publications

Ruedemann (1930) distinguishes on his map a similar unit and assigns it to his Normans Kill shale. From his description it is not clear whether his recognition of this unit is based on differences in lithology or on characteristic fossils. The fact, that he includes in his unit several outcrops (observed by him 180, 181, 183, 59, 16, 17, 55, 56, 391, 353) and graptolite localities (north 183, 271), which expose no thick and bedded greywacke, but melange of mostly shaly material instead, indicates a biostratigraphic definition by him. His map and cross-section interpret the western boundary of his unit to be a thrust fault, separating overlying older Normans Kill shale from underlying younger Snake Hill shale. Judging from the cross-section the eastern boundary was for him an essentially conformable contact between these two units.

The state map (Fisher et al. 1970) copies the spatial extent of Ruedemanns unit and assigns it to the Austin Glen member of the Normanskill Formation. Its boundary is shown as a single thrust. It is interpreted in the map of Fisher et al. (1970) as an outlier of the Taconic Allochthon to the east.

The NYS Geological Highway Map (1990) includes this unit as an erosional remnant into its Livingston thrust slice west of the Giddings Brook thrust slice of the Taconic Allochthon. It shows an age of Normanskill implying an assignment to the Austin Glen member. The shape is modified, probably due to new exposures along Rt.7 (70,71) to the south of the unit, which display exotic melange, but used to be included in the area of the unit.

Folded Thick Greywacke, (Rocky Tucks, Quaker Springs)

Reconnaissance mapping east of Saratoga Lake in the Quaker Springs Quadrangle suggested that outcrops of well-bedded, massive greywacke (232, 235. 236, 237, 238, 239) ca. 3 miles southeast of Snake Hill belong to an areally extensive bedded greywacke unit, similar to the HGZ to the south.

The main outcrop (237) in the mapping area is an abandoned, drowned quarry with no direct access. The about 100m long and 7m high quarry face could be only observed from a distance of ca. 50m across the water covered floor. The up to 2m thick, gently (<10°) dipping greywackes fine gradationally into thinner beds and shale to the top. In the NE wall just above the water surface a nearly horizontal discrete fault seems to cut bedding. To the SW complexly deformed greywacke replaces the central well bedded part. The contact appears to be abrupt and steeply dipping. Further west well bedded, apparently steeper (ca. 30°-40°) and west dipping beds are just visible from the observation point close to Rt. 76 (Lake Road). It was not possible to observe the contact between the disrupted and the western, bedded parts.

Summarizing observations mainly along Rt. 67 and Rt. 32 to the north, one may conclude that the greywackes are generally more strongly cleaved, more frequently faulted and form folds with smaller wavelengths than the greywackes in the southern HGZ.

The abandoned quarry is denoted on Ruedemanns map as a fossil locality. Unfortunately none of the relevant publications of Ruedemann (1912, 1914, 1930) yield information about the identity of the fossils at this outcrop.

Ruedemann (1930) includes the occurrences of bedded, massive greywacke in this unit into his Normanskill shale, which occupies a large area in the northern part of his map. This large area encompasses fossil localities displaying phacoidally cleaved and bedded black shale, which Ruedemann assigned to his Normanskill shale as well. Therefore Ruedemann seems to emphasize a biostratigraphic definition for the Normanskill shale in this area. Units in this thesis are distinguished by their lithology and structure. The different unit-defining criteria are responsible for the large contrast in size and shape of this unit and Ruedemanns Normanskill Shale.

The western boundary of his Normanskill shale is illustrated as a fault having a thrust sense as explained in the accompanying text. For Ruedemann, the eastern boundary seems to be an essentially conformable contact.

The state map (Fisher et al. 1970) modifies Ruedemann's map only slightly - the southeastern tip is removed and added to the SW in an area without outcrop - but distinguishes within this area an outer rim of Mt. Merino chert and an inner core of Austin Glen greywacke, both belonging to the Normanskill Formation. In the field area none of the characteristic massive black chert was found within the area depicted as Mt. Merino chert. The inner Austin Glen core includes the mentioned outcrops. The map apparently interprets this occurrence to be the core of a large syncline which constitutes a thrust-bounded outlier of the Taconic Allochthon.

The Geologic Highway Map (1990) shows these outcrops of greywacke as belonging to another outlier of its Livingston thrust slice of Normanskill age. The shape of this outlier is altered from the state map in that now a 1.5 km broad stripe east of Saratoga Lake is excluded.

Eastern Exotic Melange

The Eastern Exotic Melange is part of the broad belt of severely deformed and disrupted rocks extending from the Taconic Allochthon to the Western Exotic Melange or the HGZ and its equivalents. It is exposed by the largest outcrops in the field area and can therefore be described in some detail. These major outcrops - along the Mohawk River (54, 184, 183, 353, 271, 267, 116), along the State Canal (94, 270) and Rt. 7 (71, 72, 73) - are all located in the central part of the field area. Consequently, there the unit is best defined. To the north the outcrop situation worsens, and especially north of Anthony Kill and west of the Hudson River flood-plain outcrops are rare and small. They display scaly cleavage and block-in-matrix structures, but do not expose exotic, non-flysch lithologies. However, outcrops are rare and there is not enough information to justify the introduction of a new unit. Including these outcrops in the Eastern Exotic Melange is justified by their melange fabric, their position along strike of the central well-defined area and also the strong contrast to a well bedded shale unit to the east. Better outcrop in the Hudson River flood-plain north of Mechanicville and in the western valley slopes allow the recognition of this bedded unit. East of this bedded unit, melange fabrics are fully developed and planar slickensided veins are frequent. Melange close to and in the Hoosic River (301) bears black, massive chert. Therefore the Eastern Exotic Melange is thought to continue to the east of the bedded unit. South of the central well-defined area, in the Albany area, lack of outcrop prevents tracing the unit further south. The properties distinguishing the Eastern Exotic Melange from the easterly adjacent Flysch-Melange belt are, in order of decreasing importance, the occurrence of non-flysch lithologies, well developed block-in-matrix fabric, lack of subdomains with better preserved bedding, and, perhaps, more frequent planar slickensided quartz-calcite veins.A description of important outcrops and a summary of the observations follows.

Along the Mohawk River from Crescent Bend to the Hudson River

The Mohawk River provides along its eastern shore from about its sharp bend at Crescent to its mouth into the Hudson River the longest and most continuous outcrop in the field area (fig. 34). For its total length of about 6km only a ca. 600m long gap north of where the State Canal branches away interrupts the display of rocks. Accessibility ranges from easy to involving climbing or only by boat. Only a ca. 300m outcrop stretch west of the railroad bridge between Cohoes and Waterford and ca. 50m upstream of the dam below Crescent dam could not be visited. Outcrop height increases generally downstream from 0.5m at the northern end to about 30m maximum height at the falls. At low water, when the sometimes impressive Cohoes Falls shrinks to a barely visible trickle, the bedrock river bottom north of Cohoes Falls to the next dam is exposed and provides a large area of unusual map view of this extensive melange unit. White drying algae and mud obscure lithologic differences and hampers geologic observation, however. Most of the outcrop exposes the Eastern Exotic Melange. Only the easternmost 700m do not belong to this unit and were ascribed to the Flysch Melange. In the following the outcrop is described from NW to SE.

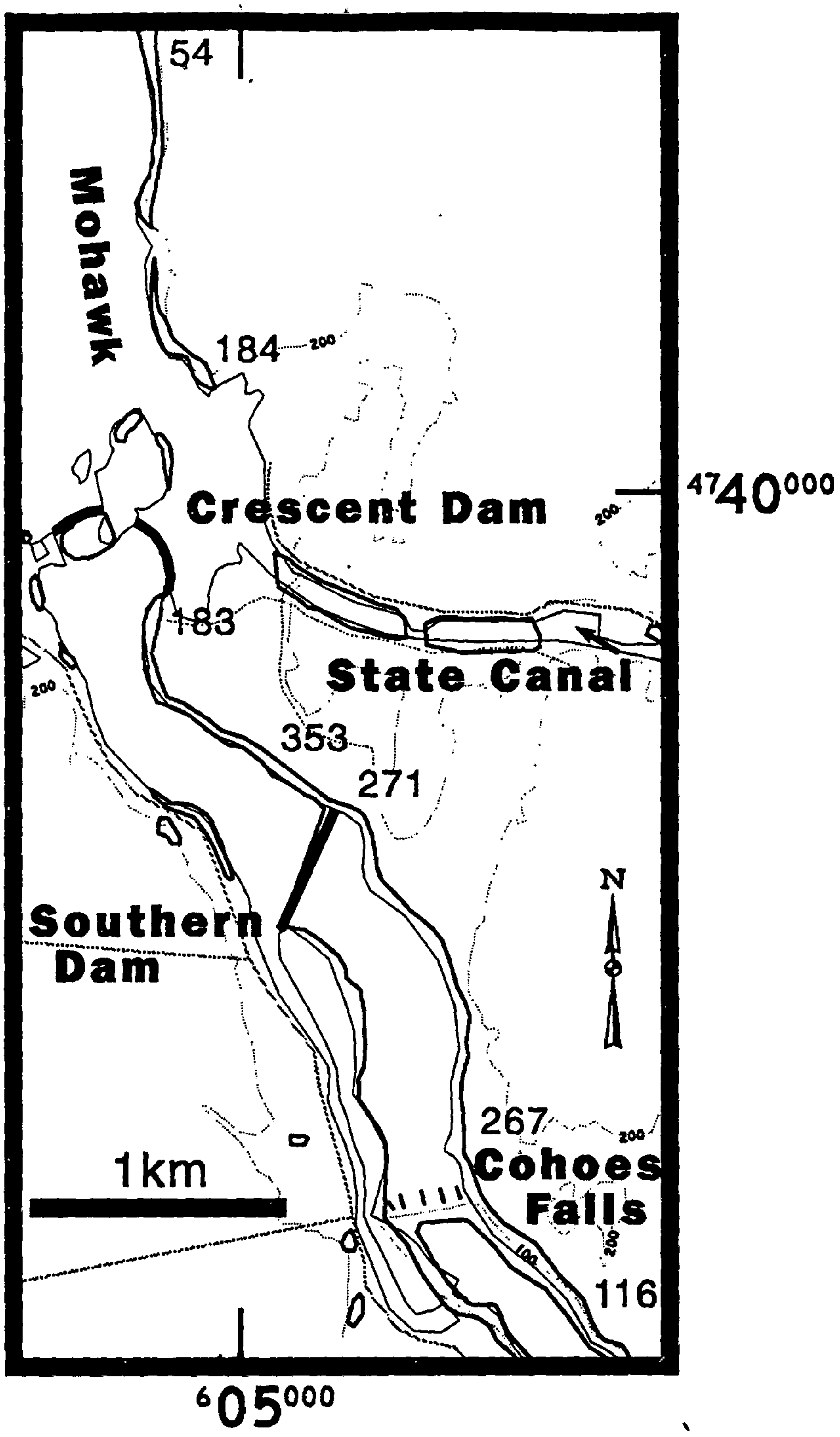


Figure 34 Position of numbered outcrops and named features along the Mohawk

A first section extends from the northern end of the outcrop, where the contact between Quaternary deposits and Medial Ordovician rocks dips below the water-surface (54), to a point east of the northern end of the Crescent dam island (184). Shale, siltstone, and minor thin greywackes (<5cm) are the principal lithologies. At the south end white weathering, at places rusty, black cherty mudstone appears in large blocks (<3m) in melange.

There seems to be a gradient in degree of disruption from north to south. In the north tight folds more frequently are preserved and cleavage planes are more often planar. In the south good scaly cleavage with "polished" shale chips and block-in-matrix fabrics were observed. The single slickensided planar vein seen dips 50°E, with the slickenlines trending 120°. There are also melange zones in the north with well developed phacoidal cleavage. The gradient between north and south is subtle - with the main difference being the large exotic blocks in the south.

South of the gap in outcrop, melange is exposed again where the eastern Crescent dam abuts against bedrock. From this point to the mouth of the Mohawk outcrop is continuous. From the dam 250m to the south a small shale beach provides good access, then, after the river bends to the southeast, the steepness of the bedrock cliff makes observations more difficult. Below the next dam to the south most of the water is channeled to the Cohoes power plant, draining the river basin for long walks.

Just below the eastern Crescent dam (183), exotic blocks of white-green and yellow-brown weathering black chert, black mudstone, red weathering, laminated, dolomitic sandstone, and carbonate are chaotically interspersed in a phacoidally cleaved shale matrix. The largest block is a chert slab about 3m long and 1m thick. The attitude of this chert slab was measured as an indication for the attitude of the general melange foliation at this location and is 005°/50E. This zone of very chaotic fabric and exotic lithologies is limited to the north by the dam and continues for about 7m to the south. The contact to the succeeding phacoidally cleaved shale with rare and thin greywacke slabs is transitional. Shaly melange with not infrequent lenses of recognizably bedded shale to the south is, in places, frequently crosscut by slickensided veins. The largest recognizably bedded shale lens in the stretch of outcrop from Crescent dam to the next dam to the south (183) was traced along strike and is about 30m long. Veining in this area is concentrated in a zone of ca. 15m length, where three measured slickenside lineations show similar trends from 90°-100°. Non-striated veins possessing euhedral crystals, which extend into small cavities, are restricted to better bedded lenses. To the south, where the cliff steepens and the river bends to the southeast, bedded zones are lacking. Two measured values for the melange foliation (averaged phacoidal cleavage) are 020°/40°E and 000°/55°E.

100m northwest of the southern dam (353, location ① on sketch map, fig. 35) a large (15m long, 0.5-1m thick) yellow-white weathering chert slab in phacoidally cleaved shale can only be accessed from the top of the cliff (located in a privately owned backlawn). The chert slab is not directly surrounded by other non-flysch lithologies . Foliations are generally gently dipping. The general attitude of the slab is about 150°/10°E, the phacoidal cleavage in the shale being approximately parallel. At the top of the cliff bedding (?) in the chert has an attitude of 170°/30°E. Striations on the chert

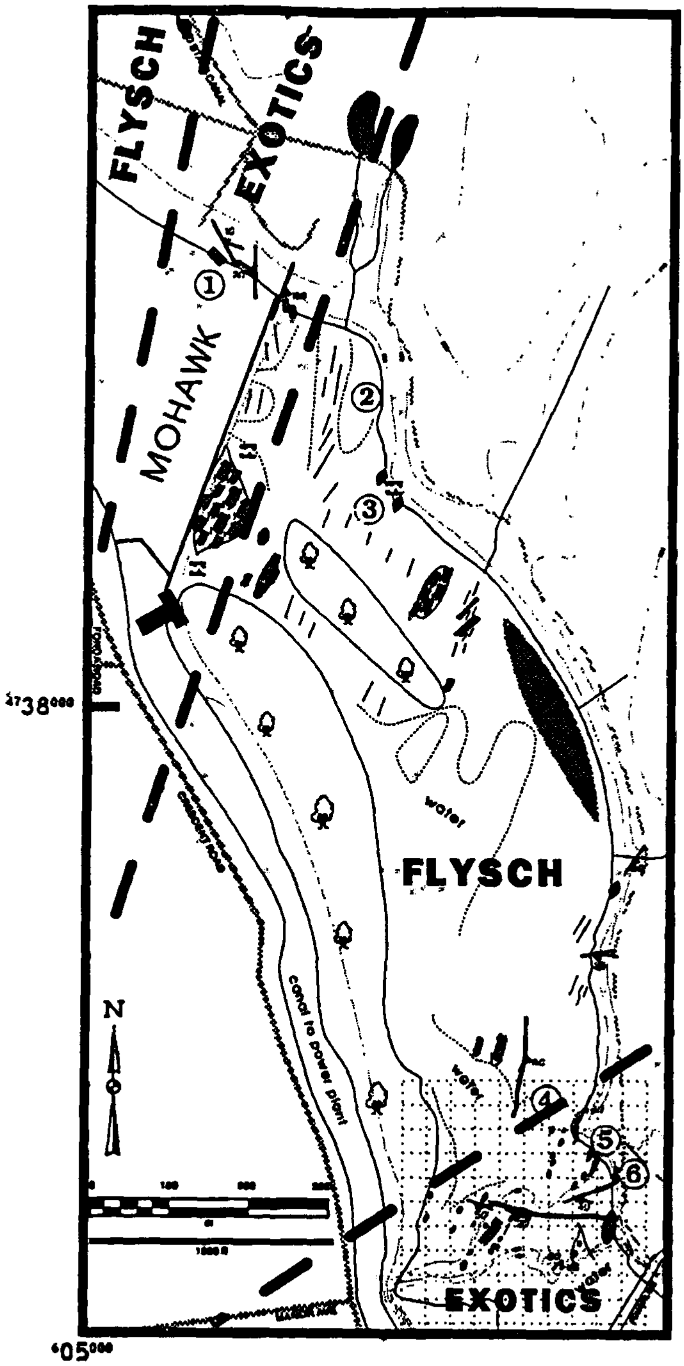


Figure 35 Sketch map of melange from Cohoes Falls to Southern Dam. The same map, in an enlarged size, is accompanied by a legend in the map pocket.

Figure 36 Yellow-white weathering chert slab has horizontal fracturing cleavage (bedding?) and overlies phacoidally cleaved shale [353]. Looking ESE.

Figure 37 Cut approximately parallel to strike of average melange foliation shows a more wavy trace of foliation than cuts perpendicular to strike. [267] Photograph by Volker Bruchert.; the author stands in front of the outcrop.

trend 110°. The lower contact between chert and matrix is exposed and partly accessible. It is sharp and dips 15°NE, striking ca. 130°. The average shale-phacoid size close to the contact is probably smaller than in the surrounding main melange body, indicated by a higher degree of utilisation of the melange as soil by pioneer plants. The chert is internally deformed beyond obvious recognition of folds, or bedding in general. Its structure and composition do not noticeably change towards the shale contact. The frequent and irregular cleavage planes in the chert tend to be parallel to the general attitude of the slab.

About 20m north of the southern dam, outcrop becomes accessible again. The flatter attitude of the general melange foliation returns here to steeper dips in the monotonous shale melange. At this location of change in attitude a very gently west-dipping slickensided calcite-qtz vein (000°/20°W) was also observed, which was preferentially weathered several cm back into the cliff-face turning into clay. The striations on it trend 120°.

The section from the southern dam to the falls is fairly easy to access. In places, especially in the central part of this section, vegetation on the cliff partly covers outcrop. A stripe of wet swamp in the central part forces one to find a way through bushes close to the cliff in order to observe the cliff outcrop. In this section three divisions may be distinguished, a narrow band of exotic melange, a broad section of mainly flysch-melange and a wide band of exotic melange.

Directly at the Southern Dam and along it, an approximately 10-20m narrow band of exotic melange is characterized by its typical assemblage, black chert, pale green shale, carbonate breccia and carbonate mudstone. The large chert slab northwest of the dam may be included in this band as indicated on the sketch map. To the west in the river bed along the dam, which is parallel to the general strike, deformed veins and a large (120m*70m) body of complexly deformed, thick, blocky greywacke beds and minor shale seem to be part of the band of exotic melange. An average value of the attitude of the general melange foliation is 020°/60°E.

Downstream a long section of mainly flysch-only melange with changing degrees of disruption follows. About 150m SE of the dam the cliff is, for a length of 100m, approximately strike-parallel (location ② on the sketch map). The impressive outcrop there reveals the chaotic, wavy nature of the melange fabric in an along-strike view (fig. 37). The overall planar phacoidal cleavage seems to become curved around a central part with thicker, blockier greywackes in a fashion similar to flow lines. The contrast to a view oblique to the strike, often characterized by a more or less well defined trace of the planar foliation (fig. 38), is remarkable. At the promontory, which marks the change from a southern to south-eastern strike of the cliff (position ③ on the sketch map), the melange includes small (< 20cm) blocks of internally heavily veined black, cherty shale. The veins or vein arrays are folded and provide up to the half of the volume of the block. They are restricted to the blocks. Also, occurrences of pebbly mudstone with a dark black shale matrix and floating flakes of bright yellow-green shale were noted there. It is not clear if some larger greywacke blocks are clasts in this pebbly mudstone. Most eye-catching are m-sized lenses of orange-brown weathering carbonaceous siltstone, brown fine-grained sandstone and black shale (fig. 41). Their exposed, apparent long axis is parallel to the

Figure 38 Cut across strike of main melange foliation at Cohoes Gorge. Evening light accentuates relief in cliff. Gently east dipping planar veins cross-cut more steeply east-dipping phacoidal cleavage. Many individual blocks can be recognized as well as bands of carbonate breccia blocks. Large carbonate breccia slab at eastern (right) limit is visible at center of cliff between vegetation and is utilized as a path.

Figure 39 Cliff of block-rich melange cross-cut by two slickensided veins (just above Cohoes Falls, [267]. Photograph by Volker Bruchert.

Figure 40 Typical greywacke block in phacoidally cleaved shale [267]. Photograph by Volker Bruchert.

Figure 41 Lens of light-brown sandstone, black shale and orange-beige weathering siltstone [267].

Figure 42 Folded calcite vein in phacoidally cleaved shale [116].

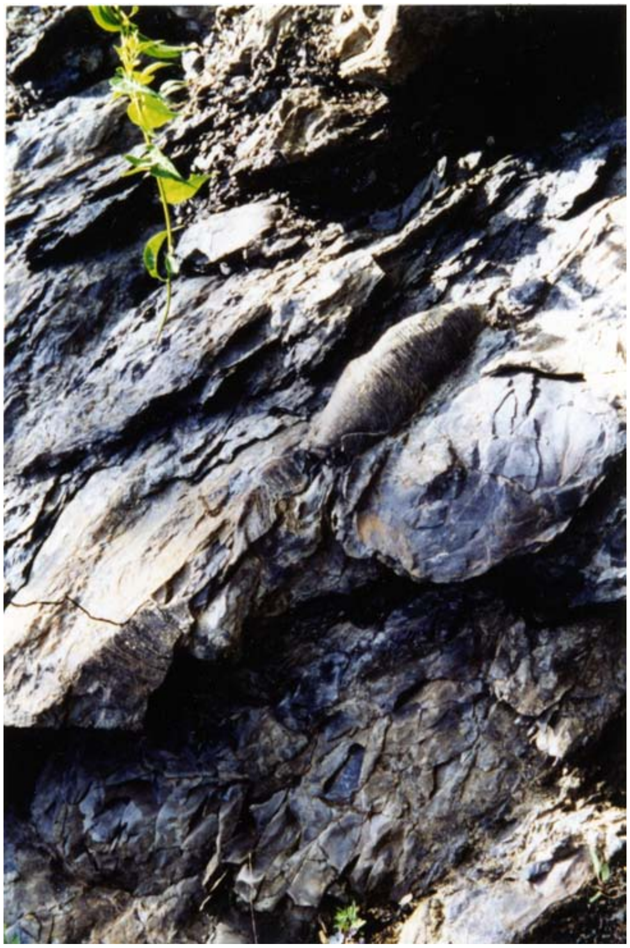


Figure 43 Discontinuous fold hinge of folded calcite vein in disrupted greywacke and shale [267].

dip-direction of the surrounding phacoidal cleavage in the shale. The various lithologies are arranged in onion-skin type zones. The interior lacks pervasive phacoidal cleavage, but is folded, cleaved and in places heavily veined.

Calcite veins, cutting the melange fabric, are partly folded, striated and discontinuous (fig. 41). These deformed veins are not internally layered. Some are string-like in form with striations parallel or perpendicular to the string axis (fig. 43). There are also planar, slickensided, layered veins. From the promontory about 50m to the SE the continuous exposure in the dry river bed shows a transition from shaly melange with a few greywacke blocks to greywacke-block dominated melange with more chaotic fabrics. This greywacke body has the shape of a 100m*40m ellipse, the long axis parallel to the general strike. Further downstream greywacke blocks are rare and slabby for about 400m. South of a small, intermittent tributary, where the cliff turns again into a strike-parallel direction, greywacke blocks become larger (<10m) and occur, in addition to slabs, in the form of sliced-off fold hinges. The m-sized lenses of orange-brown siltstone and black shale are agasin present and include deformed striated veins. Towards the prominent promontory unusual cm-thick dark-brown siltstone and black mudstone with relict bedding may have an affinity to the following broad band of exotic melange.

The position of the promontory may be a result of the change of block lithologies. Blocks are composed of black chert, sideritic mudstone (fig. 47), several kinds of carbonate breccia (position ④ on the sketch map) (fig. 46), red-weathering dolomitic, laminated sandstone and a matrix-supported conglomerate with large (<1m) spherical carbonate breccia clasts (fig. 45) in a sandy matrix which is associated with bright shale

Figure 44 Carbonate clast and shale flakes float in dark matrix of cleaved pebbly mudstone [267].

Figure 45 Spherical carbonate breccia clast in band of carbonate conglomerate in exotic melange [267].

Figure 46 Carbonate breccia block with unusually high amount of matrix [267]. Photograph by Volker Bruchert.

Figure 47 Typical red weathering, laminated sideritic mudstone [267]. Photograph by Volker Bruchert.

flakes containing pebbly mudstone (fig. 44). The conglomerate occurs in a discontinuous band at the promontory and near the edge of the falls in the western third of the falls (see map). Near the edge of the falls the largest ball-shaped carbonate breccia clast was found (1m diameter). The decrease of degree of brecciation and the increase in clast size towards the center of the ball indicates that part of the brecciation process is related to the ball-forming process. At the promontory one clast yielded an unidentified snail (maybe *Maclurites?*). Pale green shale occurs in discontinuous bands (< 0.5m wide). By far, most blocks are still greywackes (fig. 40). Slickensided veins are planar and not folded at the outcrop scale (position ⑥ on sketch map) (fig. 39). On a smaller scale (meters) they are slightly wavy or bent. The matrix shows the usual, pervasive phacoidal cleavage which rarely exhibits higher order structures like conjugate kink band geometry (fig. 48).

The falls cannot be crossed, so the section southeast of the falls to the dam at the confluence of Mohawk and Hudson River must be accessed separately. There is only one path down the steep cliff (see map in map pocket), used mainly by fishermen. The section from the falls downstream was recorded in a detailed cross-section ("Section from Cohoes Falls to the Rt. 32 Bridge" in map pocket). A supplementing map of the area shows the same section in a generalized fashion and should help in locating reference lines which are drawn in both map and detailed section. The section trends 130° on average - an optimum value would be 110° at a general strike of 020° - and shows the most interesting parts in the melange, the largest slabs of exotic material and the contact to the Flysch-Melange to the east. The drawing is based on several visits and on photography from the top of the cliff on the southwestern side (one is fig. 38). The cross-section shows the location of larger blocks and continuous, planar slickensided veins. The apparent dip of the phacoidal cleavage is indicated at the eastern end of the cross-section and remains fairly constant throughout the section, so that symbolic reiteration was found to be unnecessary and distracting. The long axis of drawn blocks are meant as a reminder for the apparent dip of the phacoidal cleavage. Except for this feature it is difficult to summarize observations in the essentially chaotic melange. It is for this reason - the low degree of redundance in the melange - that it is felt that the drawing, although fairly complete in showing positions of subzones, larger blocks, sliced-off fold hinges, and planar slickensided veins, is a spatial frame for a larger amount of structural information observable in the one km of exposed rock. Mainly for the purpose of description the section was subdivided into several subzones (see overview map in map pocket), the first one being the broad band of exotic melange just described.

The broad band of melange with exotic blocks continues across the falls. Exotic lithologies in the small (15m) bay at the base of the falls include a slab of coarse, grain-supported, bioclastic carbonate breccia with a dark carbonate matrix (1m * 0.2m) and a thick, flamed band (3m) of pale green shale and black chert blocks at the promontory at the entrance to the small bay.

To the east exotic lithologies, although not absent, become rarer, and the melange is for a distance of 120m downstream from the entrance to the small bay lithologically characterized by thick and large (<10m) greywacke blocks and slabs. Three blocks of carbonate breccia - one of them is loose and the other two are difficult to access in the cliff - , a lens of pebbly mudstone surrounded by pale green shale and a block of

Figure 48 Conjugate kink band like geometry in phacoidally cleaved shale [267]. Photograph by Volker Bruchert.

Figure 49 Large sliced off fold, steeply plunging fold hinge [116].

laminated sideritic mudstone are not localized in a narrow zone in this interval, unlike in most occurrences. It is possible that there are some more undetected small occurrences, as it is difficult for the observer, even with some experience, to stay sensitive for recognizing these blocks in the chaotic and visually demanding fabric. Also, in this zone the largest floating, steeply plunging sliced up fold hinge (3m*2m) was observed (fig. 49). It is one of at least five such fold hinges in this greywacke-rich subzone. Slickensided veins are not present.

The succeeding 100m of outcrop downstream show less greywacke blocks and several planar slickensided veins. Their apparent dip allows a distinction between two classes, veins with an apparent gentle, eastern dip (more gentle than the phacoidal cleavage) and nearly vertical veins. Blocks in the form of floating fold hinges occur regularly. There are also short (< 1m), discontinuous, non-slickensided veins (the "extensional" veins labelled on the section) with no obvious preferred orientation. One of the largest greywacke blocks (10m*1m) marks the transition to a section of 40m length downstream with only thin greywackes and frequent, not-slickensided veins.

The succeeding 200m of exposure downstream contain the largest slabs of carbonate breccia seen in the outcrop. Three bands of apparently aligned carbonate breccia blocks can be recognized. The most western one reaches down to accessible height at a small promontory which is difficult to pass at higher water stands (fig. 50). At least four large (>1m) blocks can be seen looking upwards. The band defined by the apparently aligned blocks has a more gentle dip than the general melange fabric defined by the average phacoidal cleavage. Towards the next carbonate breccia band several blocks of

Figure 50 Band of carbonate breccia blocks slightly more gently dipping than phacoidal cleavage in surrounding shale [116].

Figure 51 Large massive greywacke block in phacoidally cleaved shale resting on top of large carbonate breccia slab [116].

recognizably bedded siltstone and interlayered shale are difficult to recognize because they do not exhibit such a strong contrast with the surrounding phacoidally cleaved shale matrix as the compact carbonate breccia or greywacke blocks. The siltstone-shale interbeds have similar thicknesses (<3cm), giving the blocks a characteristically striped brown-black appearance. The next band of carbonate breccia blocks is somewhat less well developed. It contains smaller blocks and is more discontinuous. It is accompanied by little pale green shale, which is maybe easier to identify and may help in locating the carbonate breccia. To the southeast several larger greywacke blocks (< 1m) and two scattered carbonate breccia blocks herald the occurrence of the thickest and longest carbonate breccia slab. It is up to 4m thick and occupies the whole height of the cliff essentially uninterrupted by the melange matrix. The path leading from the upper edge of the cliff down to the river utilizes the top of the slab, so it cannot be missed. The facies does not change drastically throughout the slab. The grey, angular, but slightly rounded, micritic, sometimes fossiliferous and shelly clasts are a few cm (<10cm) in size and float in a bright-brown-grey micritic matrix. Approximately 3m upstream of the bottom third of the slab another separated slab displays few, but large (20cm) dark-brown-red weathering dolomitic, better rounded, equidimensional clasts surrounded by a bright-whie weathering micritic matrix. Striated foliations in the main slab demonstrate internal deformation. Veins are not obviously common in the carbonate breccia. The isotropic texture of the breccia restricts recognition of bedding and therefore more detailed structural analysis. One of the largest greywacke blocks in the melange is situated structurally directly above the breccia slab, separated from it by thin rind of phacoidally cleaved shale and in places bound by thin calcite veins (fig. 51). The coarse greywacke is very massive and isotropic, lacking bedding, cross-bedding or shaly interbeds. Besides the size of the angular block (2.5m*2.5m) its equidimensional shape is also unusual. In the bottom third of the cliff, thick bands of pale green shale structurally overlie the breccia slab. The pale green shale contains chert blocks and further downstream red-weathering blocks of laminated sideritic mudstone and siltstone. Also, it seems that the band of exotic lithologies contains more and larger pyrite concretions than the shale-greywacke melange. This observation is supplemented by similar observations in occurrences of exotic melange (at the falls or at K-C-Canary, 66), but is still tentative due to the general rarity of pyrite concretions. Any conclusion following from this observation should be made cautiously in view of the wide range of conditions in which pyrite can form. The upper end of the breccia slab seems to be cut off by a gently east-dipping slickensided quartz-calcite vein. The vein is preferentially weathered and can be traced down to the cliff bottom. It intersects the river at a small promontory, which is difficult to cross at higher water levels (for orientation data see map). Close to the bottom it thickens to about 4cm and is layered. The quartz-calcite layers are separated by thin sheets of striated dark material (shale and/or insoluble residue). At the same position, another slickensided vein branches away to the top and may connect to the next structurally higher vein or may die out. Further downstream to a point where the powerline crosses the river, blocks of laminated, sideritic mudstone, dark-black, compact mudstone and black chert demonstrate continuity of the broad band of exotic melange. A block of black, compact mudstone contains a *Nemagraptus gracilis* fauna (of Riva

1974, Riva pers. communication to Kidd 1983). Orange-rusty weathering colors of the prevailing shale matrix seem to intensify eastward towards the contact with the Flysch-Melange. The contact is gently east-dipping and sharp. It is not clear whether it is defined by a weathered slickensided vein or only by the lithological difference. East of the contact grey, monotonous shale-melange contains a few greywacke slabs only in the vicinity of the contact.

Summary

Summarizing these observations some important properties of the Eastern Exotic Melange as exposed along the Mohawk River can be stated. Lithologically, the melange is dominated by shale and siltstone. Non-flysch lithologies are systematically assembled in more or less well-defined zones. The following lithologies were observed in these zones:

- pale green shale;
- massive black chert, in places white or yellow brown weathering;
- laminated, sideritic mudstone;
- red weathering, laminated, dolomitic sandstone;
- several kinds of carbonate breccia;
- matrix supported carbonate conglomerate exhibiting large (<1m) spherical carbonate breccia clasts in a sandy matrix;

- coarse, grain supported, bioclastic carbonate breccia with a dark carbonate matrix;
- pebbly mudstone with a dark black shale matrix and floating flakes of bright yellow-green shale.
- lenses of orange-brown weathering carbonaceous siltstone, brown fine-grained sandstone and shale;

Coarse and thick greywacke beds seem to have an affinity with the non-flysch lithologies. Structurally, there is a persistent fairly steeply east-dipping melange foliation, defined by the phacoidal cleavage of the shale and orientations of slabs. Along strike the horizontal trace of this foliation is much less consistent in orientation than the steeply east dipping trace in section across strike. The constant attitude of the large scale (> 5m) melange foliation contrasts with a small scale chaotic blocks-in-matrix structure. Not infrequent sliced-off fold hinges can plunge steeply and have an axial plane generally parallel to the main fabric. There are similarly folded veins. Planar, up to a few cm thick, layered slickensided quartz-calcite veins crosscut the melange fabric and can be traced for more than 100m. Whereas some are vertical, most of the slickensided veins are gently to moderately east-dipping.

Along Rt. 7 from the Rt.9 Ramp to Miller Road Bridge

The exposure of rocks begins at the east-bound ramp from Rt.9 on to Rt.7 and continues eastwards with heights between 2m and 5m on the northern and southern side of Rt. 7 for 750m as the road cuts through a small bedrock ridge (fig. 52, 53). 300m further east, the construction of the road exposed bedrock for another 350m to the east, after it traversed a small valley which is responsible for the outcrop gap. On the northern side of the road-cut outcrop ends ca. 100m west of the Miller Road bridge, on the southern side ca. 10m east of the bridge.

From the ramp to the water-tower north of the road m west of the Miller Road bridge the road-cut strikes 100°, then it turns slightly to the south and strikes 108°. Additionally to this almost perfect orientation across strike, foliations dip very steeply to vertical in the eastern two thirds of the outcrop, so that a maximum of structural thickness can be examined.

Three sections are distinguished. From west to east these are a narrow (30m) band of melange containing small amounts of non-flysch lithologies, a broad band (500m) of shale-greywacke melange, and, for the rest of the outcrop to the east, well developed exotic melange with abundant blocks of sideritic laminated mudstone and siltstone, black chert, and in places broad flames of pale green shale.

At the Rt. 9 ramp and where it joins the main highway (Rt. 7) careful observation reveals occurrences of pebbly mudstone and in places frequent pale green shale in the heavily veined melange (see range 1 on fig. 54). The rounded, small clasts (<3cm) of the

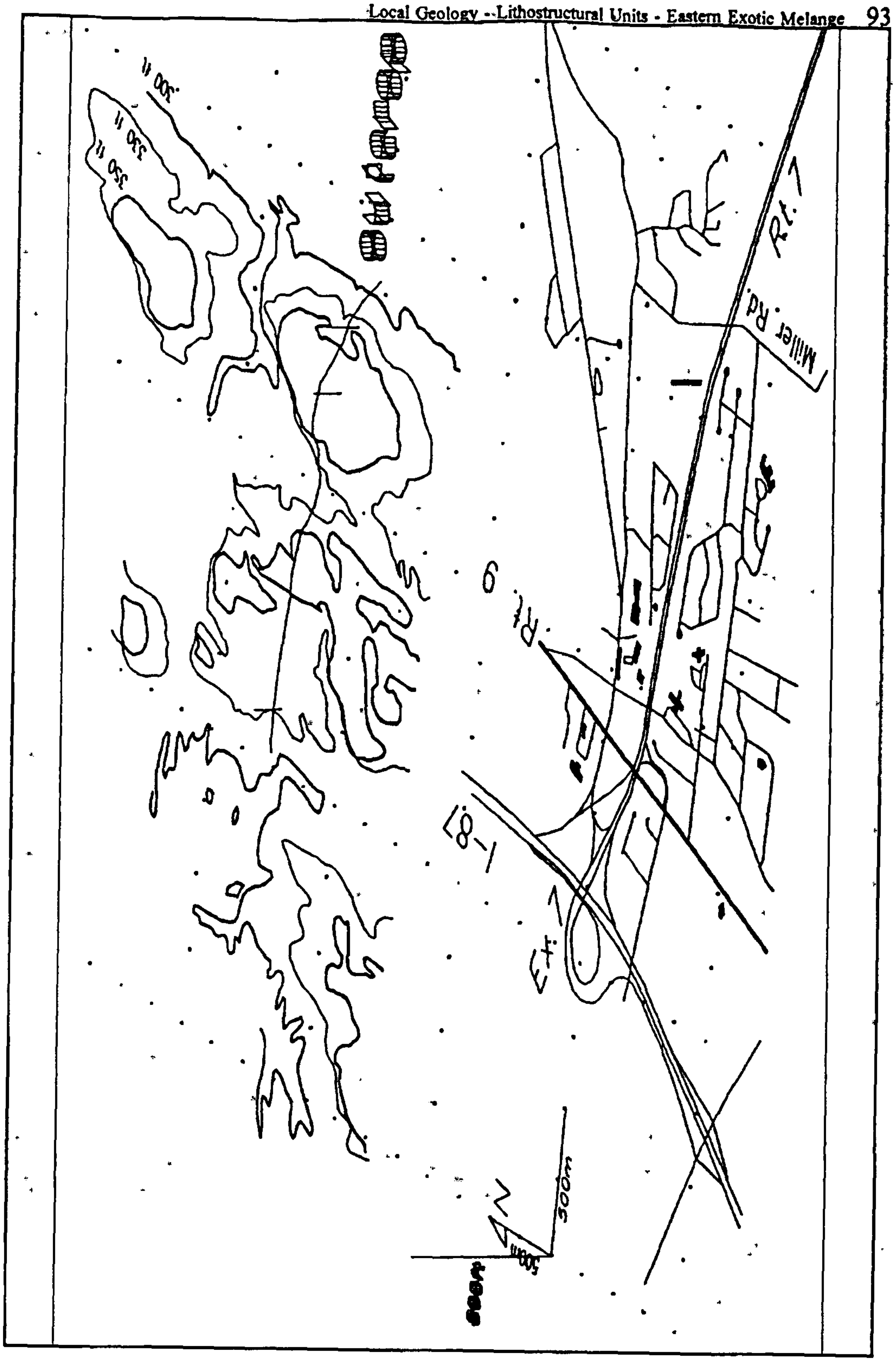


Figure 52 Perspective view of roadcut along Rt. 7 from Rt.9 ramp to Miller Road Bridge and vicinity. Topography floats above road map.

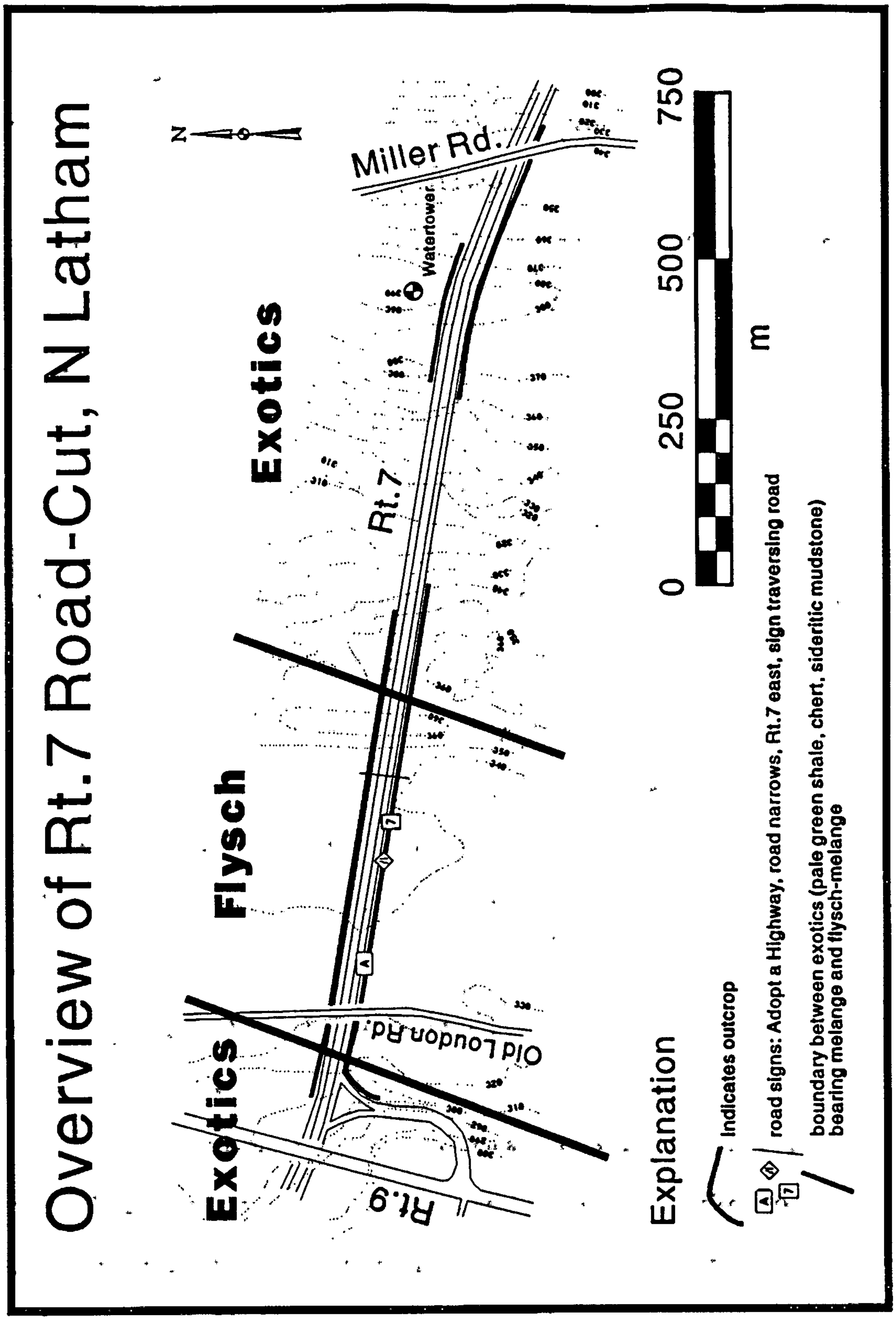


Figure 53 Overview map of Rt.7 outcrop indicating in more detail position of outcrop, of geographic references, and of geologic units.

pebbly mudstone consist of carbonate, red weathering sideritic mudstone and dark green weathering, grey quartzite. The clasts float in black shale matrix. The pale green shale is mostly interspersed with black shale (best visible if rock is wet), but occurs also in blocks. On the north side close to the western limit of the outcrop a 0.5m to 1m broad zone of pale green shale has an attitude of 030°/60°E and is irregularly foliated parallel to its boundaries by partly polished appearing surfaces. There is a large (5m) purple-red weathering greywacke block just east of this zone. Also there are dark-red weathering sideritic mudstone blocks in the northern cut. Otherwise this zone lacks larger slabs or blocks.

This minor band of exotic melange is followed to the east, to about 15m east of the Old Loudon Road bridge, by melange consisting entirely of shale (range 2 on fig. 54). Bedded blocks of shale bounded transitionally by phacoidally cleaved shale are up to 3m in size. Bedding is about parallel to the cleavage. Slickensided quartz-calcite veins are abundant (every few meters a thicker (<4cm) one; thinner ones are much more frequent) towards the bridge and thin out to the east. Between the Rt. 9 ramp and the Old Loudon Road bridge A. Hiller (unpub. data) found 30 locations showing slickensided veins suitable for measurement of attitude and striation direction. They can be found, however, throughout the whole outcrop.

East of this zone the melange remains dominated by shale, but fine grained thin greywacke slabs begin to show as blocks (range 3 on fig. 54). They are also dark in color and mainly recognizable by their bedding and the small difference in grainsize.

About 10m west of a "road narrows" traffic sign (ca. 300m east of the bridge abutment) the first thick (<1m) and massive slabs of greywacke appear rather abruptly (range 4 on fig. 54). They are still fine to medium grained and usually crossbedded. The disrupted greywacke slabs, coherent over maximum distances of about 5m, dominate over phacoidally cleaved shale. Close to the traffic sign, one of the rare coarser greywacke slabs bears layers of fossil hash (brachiopod-crinoid material).

East of the "road narrows" traffic sign greywacke slabs become again less frequent and thinner (range 5 on fig. 54). Towards a "7 east" traffic sign (about 350m east of bridge abutment) a thick quartz-calcite vein with the largest euhedral crystals (<5cm) appears. Cloudy mineralisation affects a width of about 2m.

About 15m east of the "7 east" traffic sign (365m east of bridge abutment) greywacke starts to occur more frequently and in larger slabs (range 6 on fig. 54). Bedded packages or slices are up to 1.5m thick and 4m long. East of the large two-lane traffic sign bridging the road there is another greywacke bed with fossiliferous hashy layers, located east of where a large vertical slab has an unusual strike (at a small angle with the road).

The contact with the large section of non-flysch blocks bearing melange (fig. 55) is transitional, although the distinguishing properties between the shale-greywacke melange and the exotic melange are distinct and easy to recognize. East of the contact the melange lacks larger slabs of bedded greywacke and has a much stronger block-in-matrix aspect. Lithologically, red-weathering sideritic mudstone blocks and bands of pale green shale signal the entrance into the melange which bears exotic material (fig. 56). The pale green shale occurs in bands up to 0.5m wide. Greywacke is still fairly frequent and seems to be coarser-grained than in the western part, even though it is preserved in smaller

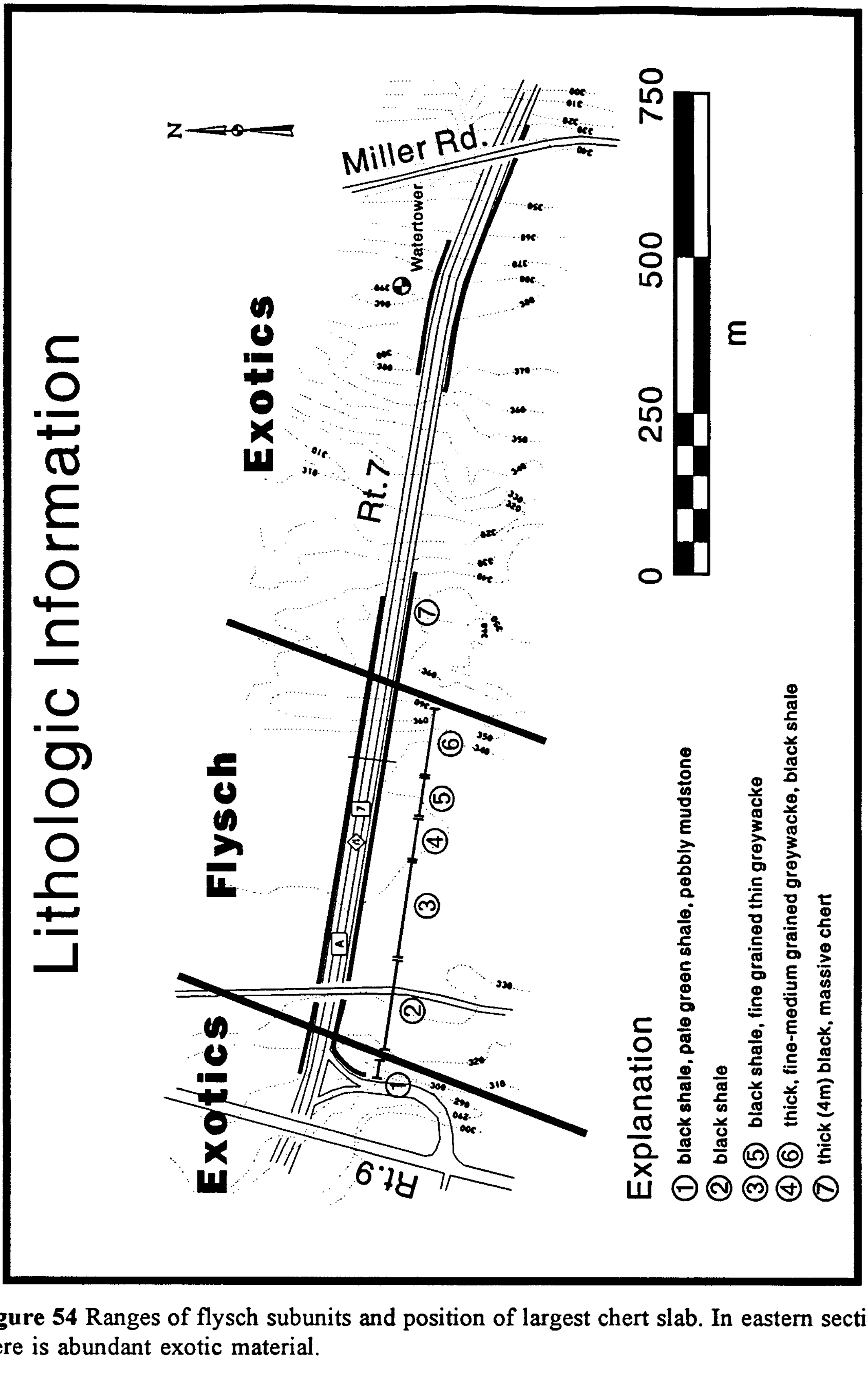


Figure 54 Ranges of flysch subunits and position of largest chert slab. In eastern section there is abundant exotic material.

Figure 55 Steep east dips in exotic melange at Rt. 7 [71]. Black stripe left of center is large slab of massive black chert, other stripes are wet rock. Looking north, width of photograph ca. 50m.

Figure 56 Cm-thick bands of pale green shale within dark phacoidally cleaved shale [71].

blocks. About 50m west of the eastern outcrop limit, just west of a small gap in the outcrop, an approximately 4m thick, black, massive chert slab seems in places brecciated and to consist of fitting chert clasts.

The same lithologic association - greywacke, pale green shale, black, massive chert and red sideritic mudstone - provides the main melange constituents in the eastern part of the outcrop. On the south side of Rt.7, east of the Miller Road bridge the only carbonate block (beige weathering micritic mudstone) was found. Field notes from an early first visit indicate the occurrence of a red conglomeratic sandstone between small green road marker signs 1155 and 1154 (bottom four digits) west of a thick chert slab.

The outcrop also provides interesting structural information. The structural features are described starting at a scale of the size of the outcrop down to a scale of the size of the width of veins.

The dip of the melange foliation in the outcrop changes distinctively from west to east (see fig. 57). At west end of outcrop dips are gentle (30°) and steepen somewhat to the east. In the vicinity of the "7 east" traffic sign dips are gentle again. To the east - still west of the large two-lane sign - the melange foliation becomes steep (>60°) to vertical and keeps this attitude in the eastern remainder of the outcrop. All of the exotic melange is steeply to vertically dipping. However, the boundary between the gentle and steep domains does not coincide with the boundary between exotic and flysch melange. The boundaries are apparently not related. It is more likely that the rotation of vertical greywacke slabs into the unusual strike of 055° close to the boundary between exotic and flysch melange is related to the boundary creating process.

As mentioned above, the characteristic block-in-matrix structure is well developed

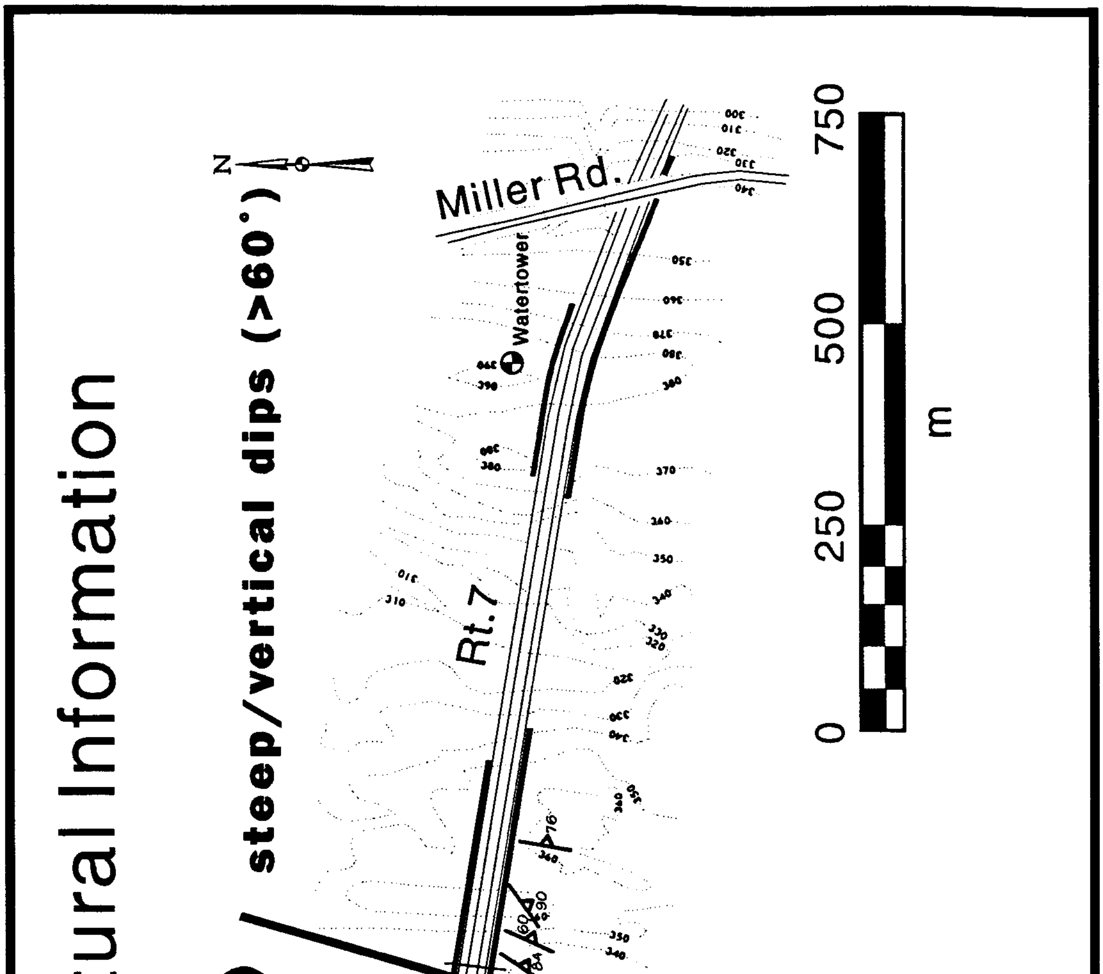


Figure 57 Variation of attitude of melange foliations along Rt.7

Figure 58 Sliced off fold hinge in phacoidally cleaved shale truncated by slabby greywacke blocks [70]. Looking south.

Figure 59 Subvertical, faulted greywacke block in phacoidal shale [70].

in the exotic melange, whereas blocks in the flysch melange (fig. 58) are often larger slabs, some of which were recognizably faulted and displaced (fig. 59). In the exotic melange, sideritic mudstone and greywacke blocks are typically smaller and rhombohedral in form. The largest blocks, which are slab-like, are formed by black massive chert. The pale green shale occurs in mm to 0.5m wide bands parallel to the phacoidal cleavage, and rarely in blocks. The greywacke slabs in the flysch melange are cut by both slickensided veins and phacoidally cleaved shale. For some slabs it is possible to identify them as formerly belonging together. Tentatively, thin slickensided veins seem to be responsible for smaller, better recognizable, offsets than the phacoidally cleaved shale. The faults displacing greywacke slabs indicate an east over west shear sense (fig. 60). They are typically of Riedel type if interpreted as part of a shear zone in which the main phacoidal cleavage is parallel to the shear zone boundaries.

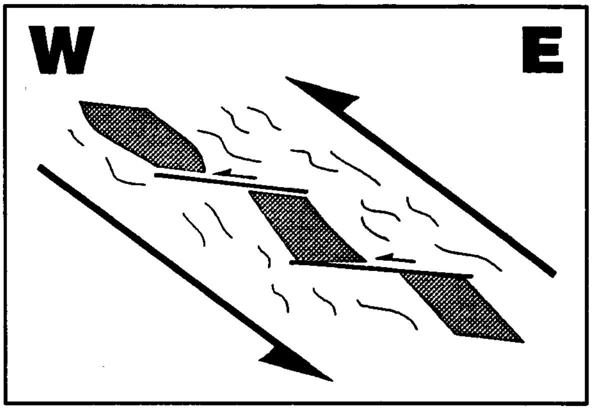


Figure 60 Schematic sketch of faulted greywacke slab in phacoidally cleaved shale.

Petrologic differences between greywackes from flysch melange and exotic melange

Greywackes in the melange containing the assemblage of non-flysch lithologies appeared in the field to be coarser producing rougher weathered surfaces compared to greywackes from the western flysch section. Also exposed edges seem to weather to more

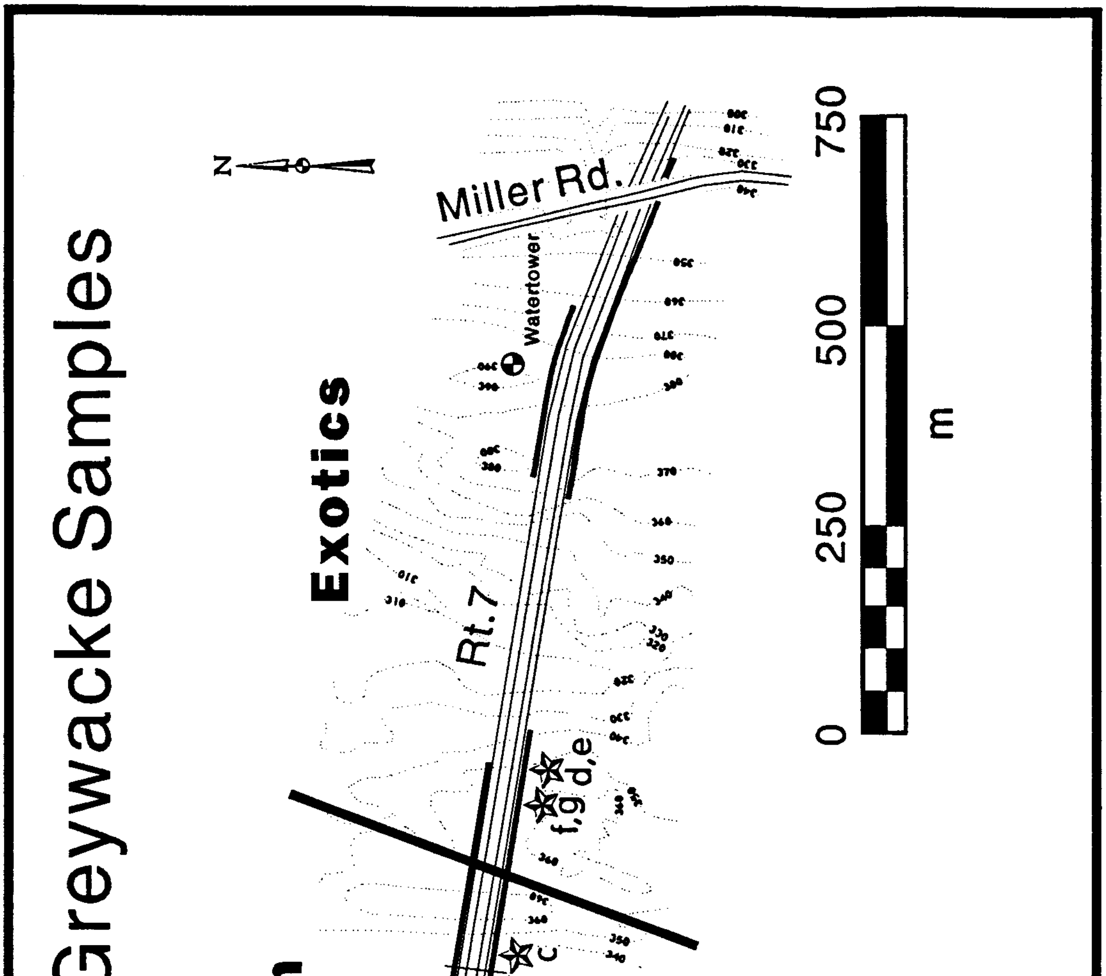


Figure 61 Locations of greywacke samples in the flysch and the exotic section.

rounded shapes. In an attempt to further constrain these differences petrologically, seven samples of greywackes were selected, three from the flysch section and four from the exotics-bearing section (fig. 61). As these greywackes were to be examined in thin sections, the sampling process aimed at coarse greywackes. During sampling with special concern towards grain size, the previously noted grain size difference was confirmed. Sufficiently coarse samples were found with much less difficulty in the "exotic" section than in the flysch section. This selection process also means that the coarsest fraction of the flysch-greywackes were compared with a coarse, but not necessarily the coarsest fraction of the "exotic" greywackes. Even so, the grain size difference could be confirmed in the thin-sections. It was found that average grain sizes in the well sorted flysch samples are generally less than 0.15mm. The "exotic" samples are in contrast very poorly sorted. Grain sizes are estimated to be equally distributed between 0.25mm to 1mm. Petrologically, differences in the lithic fraction were particularly notable. In the flysch samples shale clasts provide the majority of the lithic fraction. They are supplemented by minor chert and polycrystalline quartz. The abundant shale gives the section a dark color macroscopically. The "exotic" thin sections contain a larger variety of lithics, including slate and gneiss. In one "exotic" sample section the largest clasts are alkali-feldspars and not quartz.

Point counting results and summary

A point counting analysis (see appendix 1) of three thin section from "normal" greywackes from the flysch only section and four "exotic" greywackes from the section characterized by systematic assemblages of non-flysch lithologies showed overall similar modal abundances of the counted categories. Lithics other than shale, chert or polycrystalline quartz were only found in the "exotic" sections, but are rare. All clast counting categories except quartz/kspar were found to be useful in several plots discriminating "normal" and "exotic" greywackes, specifically the low abundance categories twinned plagioclase and other lithics/heavy minerals. On all plots groupings could only be accomplished by defining a boundary line and never suggested itself by clustering. The point counting analysis confirmed the previously made qualitative distinction between the two different kinds of greywackes in plots involving the depositional parameters shale clasts and/or matrix/cement. In the field a difference was initially recognized by the coarser grain size, rougher surfaces, a higher degree of rounding of exposed edges of blocks and generally higher immaturity of the "exotic" greywackes. Whereas these differences in thin section and field characteristics suggest mainly a difference in the depositional setting, the higher amount of other lithics and twinned plagioclase in the "exotic" sections hints at a difference in provenance, but is difficult to evaluate quantitatively due to their low abundance.

Along the State Canal from Guard Gate No. 2 to 350m east of Guard Gate No. 1

The State Canal branches away from the Mohawk just north of Crescent Dam (see location map) and cuts at length of 800m through a bedrock ridge (94, 270). The exposure can be directly accessed only just east of Guard Gate No. 2 and No. 1. Elsewhere the cut is a bedrock cliff up to 8m high which emerges vertically from the water surface and is only possible to observe from a distance. The exposure north of the canal enjoys better light than the south side. The north side east of the eastern Guard Gate (No. 1) was recorded in a series of photographs (fig. 62) taken from the top of the cliff on the southern side. The western part from Guard Gate No.2 to No.1 strikes 110°, the eastern part from Guard Gate No. 1 to the east strikes east-west.

The characteristic assemblage of exotic lithologies was observed all along this cut. Pale green shale and red weathering sideritic mudstone were observed at the accessible locations and on top of the cliff. White weathering, compact, black chert occurs in large slabs and can be recognized from a distance. A black chert block was also found on top of the cliff.

Due to the restricted access it was not possible to separate exotic melange and flysch melange zones along the cut. Judging from the apparent abundance of exotic material, flysch melange zones are expected to have the same or less structural thickness than exotic melange zones.

The outcrop is only a short, along-strike-distance (500m to 1km) away from the Mohawk outcrop west and east of the Southern Dam (see location map). Correlating distinct zones in both outcrops was not possible. The abundance of exotic material along

Figure 62 Steeply east dipping melange fabric at State Canal cut, north side [270]. (view corrected from mirror image included in thesis)

the State Canal and only localized occurrences of exotic material along the Mohawk River make a distinct contrast. The lack in continuity along strike on this scale (1km) suggests a complexly interwoven pattern of flysch and non-flysch material in this melange belt.

Dips of the phacoidal cleavage are between ca. 50°E and 70°E throughout this outcrop. A single tight synform-antiform-synform ("W") fold combination formed by chert was seen, which has an amplitude and wavelength of approximately 3m. The axial plane is also steeply east dipping.

Summary of observations

The main outcrops in the Eastern Exotic Melange enable one to form a certain idea of what the melange is derived from and what its internal structure is like. It consists dominantly of shale, siltstone and fine grained greywacke. It is characterized by occurrences of a specific assemblage of non-flysch material. Fig. 63 gives a complete list of observed non-flysch lithologies. Non-flysch material is abundant in places and is systematically assembled in zones. In these zones non-flysch lithologies occur as blocks in a shaley matrix. Greywacke blocks are frequent in these zones as well. Petrologic work on greywackes from Rt.7 suggests that there is a discernable systematic difference between those "exotic" greywackes and greywackes from flysch melange. It is suggested that the "exotic" greywackes are coarser grained and contain more lithics and matrix. The non-flysch melange zones can have a width from 20m to 500m across strike and are volumetrically important. Judging from three extensive outcrops they may be as abundant as shale-greywacke-melange. Bands of flysch and non-flysch material are likely to be interwoven at a scale of less than 1 km.

- pale, green shale, mostly in flames or interspersed, rarely in blocks
- in places white or yellow brown weathering massive black chert, in places brecciated and consisting of fitting chert clasts, without matrix
- laminated, sideritic mudstone
- white weathering, at places rusty, black cherty mudstone
- red weathering, laminated, dolomitic sandstone
- several kinds of carbonate breccia
- matrix supported carbonate conglomerate with large (<1m) spherical carbonate breccia clasts in a sandy matrix
- coarse, grain supported, bioclastic carbonate breccia with a dark carbonate matrix
- beige weathering micritic mudstone
- pebbly mudstone with a dark black shale matrix and floating flakes of bright yellow-green shale
- pebbly mudstone with rounded clasts of carbonate, sideritic mudstone, dark green weathering, grey quartzite
- lenses of orange-brown weathering carbonaceous siltstone, brown fine-grained sandstone and shale

Figure 63 List of exotic lithologies in Eastern Exotic Melange

There is a more or less well defined melange foliation defined mainly by phacoidal cleavage of matrix-shale, orientation of slabby blocks and axial planes of sliced off fold hinges. The foliation dips moderately to steeply to the east. The trace of this foliation along strike is much less consistent than the trace across strike. Slickensided planar quartz-calcite veins are frequent, in places abundant, and crosscut the melange fabric.

North and South of the central well-defined area

To the north extensive zones containing abundant non-flysch lithologies were not recognised probably due to the lack of extensive outcrops. Black massive chert (301), large (2m) and frequent greywacke blocks (297, western part of 243) and frequent planar slickensided veins (294) suggest correlation along strike with the well defined central area of this Eastern Exotic Melange unit. Approximately 500m south of 297 the topographic map shows sufficiently steep gradients of small stream valleys to expect bedrock exposure. These have not been visited by me. South of Rt.7 the few existing outcrops (16, 39, 217, 2) show phacoidally cleaved shale and no exotic lithologies.

Graptolites and age

Ruedemann (1930) shows on his map of the Capital District seven graptolite localities in this unit. It was not possible to recover from his report graptolite contents of single outcrops. The localities belong to both his Normanskill shale and his Snake Hill shale.

Riva (1983, pers. communication to Kidd) found *N. gracilis* fauna and *C. americanus* fauna close to the Cohoes Falls and *N. gracilis* fauna (all after Riva 1974) in a black mudstone block close to the boundary with the Flysch Melange in this exposure (see detailed cross-section).

The area described in older publications

The state map (Fisher et al. 1970) does not show a similar unit. Most of it is included in the Canajoharie Shale, the same unit which is assigned to my Undeformed Flysch, Northern Shale unit. All of the Mohawk outcrop west of the Falls is assigned to the Austin Glen Greywacke apparently because Ruedemann drew at this position a boundary to separate his, in this case obviously biostratigraphically defined, Normanskill from his Snake Hill. With the name Austin Glen the lithologic aspect (massive greywacke) is emphasized and therefore there is no reason left to include all of the Mohawk River outcrop west of the falls. Close to the junction of Road 86 with 32 south of Mechanicville the 1970 state map shows a small thrust-bounded outlier of Mt. Merino formation (112, 113). No massive black chert could be found there. North of Anthony Kill and west of Mechanicville an olistostromic deposit is distinguished. No especially separable melange facies, including olistostromic deposits, was recognised there.

The NYS Geological Highway Map (1990) includes all of this unit into a unit which comprises Snake Hill shale and Taconic Melange.

Correlation with Vollmer's units

Vollmer (1981) divides his Taconic melange into three units, a western belt, an eastern belt and the Normanskill melange. The western belt corresponds to both the Western Exotic Melange and the Eastern Exotic Melange of my mapping, as south of Albany there is no separating massive, bedded greywacke within Vollmer's western belt. Vollmer describes melange fabrics which were also recognised within the lithostructural unit concerned and found exotic lithologies, namely black chert, as "blocks and sheets within the Taconic melange" (Vollmer 1981, plate 1A). The western belt also contains his Normans Kill melange. It is composed of complexly deformed thick greywacke.

Bedded Shale

Several outcrops north of Mechanicville (341, 300, 224, 225, 226, 227, 342, 360, 361, 362, 243, 244, 245, 349, 350, 351, 345, 346, 347, 344) and one just south (298) show bedded shale, siltstones and greywackes.

Lithology

Shale is dominant. Abundant fine-grained greywacke was seen only at 226 and has thicknesses smaller than 10cm. The largest outcrop at Schuyler Creek (243) provides a contact to melange to the west and exposes at a length of 400m gently-east-dipping bedded, essentially undeformed shale.

Deformation within the Bedded Shale in the Stillwater area seems to increase to the east from unfolded (243), tightly folded (226, 360) and in places cleaved (225), to isoclinally folded (224) and in places disrupted (361).

Structure

Deformation ranges from unfolded and gently dipping (243) to isoclinally folded and partly disrupted (361, 244, 345).

225 is the only outcrop in the field area which exhibits pencils in flysch. It is well developed and clearly a result of the intersection of bedding in the shale with closely spaced slaty cleavage. The pencils are thin and a few cm long. Bedding is 020°/20°W,

cleavage 010°/85°E. Just 300m to the north (241) the same slaty cleavage reappears and demonstrates its locally pervasive nature. No slickensided veins were observed in these exposures.

Western contact with the Eastern Exotic Melange

The contact of the bedded shale unit exposed in Schuyler Creek (243) is transitional and has a width of about 10m. The melange has all the characteristic properties (e.g. phacoidal cleavage, block-in-matrix structure and slickensided planar veins). The shale away from the contact is essentially undeformed. A push-up structure - two discrete conjugate thrusts buckling shale and thin greywacke to a small antiform - indicates horizontal shortening approximately 10m east of the contact (fig. 64). The contact of bedded material with the easternmost phacoidally cleaved shale has an attitude of about 030°/25°E. Lineations on the slickensided veins crosscutting the melange strike 145° and 120°.

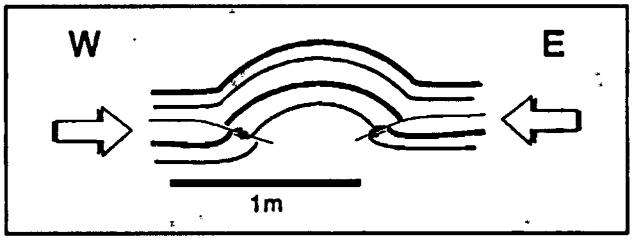


Figure 64 Schematic sketch of push-up in bedded shale close to contact with melange indicating horizontal compression.

Eastern contact with the Eastern Exotic Melange

The south tip of the island north of Green Island and west of the State Canal Park is believed to expose the contact of the bedded shale with well developed melange to the east. Exposure there is restricted to some cm above the water surface and indicates a broad transition (100m).

Summary

In places extensively preserved bedding, lack of veining and occurrence of slaty cleavage characterize this unit structurally. In this respect it is similar to the HGZ. The western contact with the surrounding melange is sharper than the eastern contact.

Graptolites and age

Ruedemann (1930) found fossils at outcrop 226. He included the locality in his Normanskill shale as the southernmost fossil locality. Despite the strategic importance of the locality as boundary defining, he did not elaborate on the fossil content in any of his relevant publications (1912, 1914, 1930). Apparently they were characteristic enough to enlarge significantly the area assigned to his Normanskill shale.

Otherwise Ruedemann (1930) depicts all of the Bedded Shale unit as his Snake Hill shale. At Schuyler Creek (243) he draws at the position of the contact between melange to the west and bedded shale to the east a boundary which separates for him Normanskill shale and Snake Hill shale respectively.

The area described in older publications

The State map (Fisher et al. 1970) depicts the area of the Bedded Shale as Canajoharie Shale, thus not recognizing any of the above distinctions.

The NYS Geological Highway map (1990) includes the unit concerned in its Snake Hill shale, which is also assigned to all other units described in this thesis except the HGZ and its northern equivalent.

Vollmer (1981) did not recognise a similar unit south of Albany.

Flysch Melange

East of the Eastern Exotic Melange a broad belt of melange and small bedded slices (domains?) contains almost no non-flysch material, but only shale, siltstone and thin greywacke. Most outcrops were found on the Troy South (260, 86, 87, 88, 89, 90, 91, 134, 214, 215, 216, 217, 392, 92, 93, 117) and Troy North quadrangles (118, 119, 120, 121, 74, 75, 76, 77, 122, 123, 124, 125, 126, 127, 128, 129, 130, 131, 132, 133, 266, 276, 265, 52, 116 east, 274, 340, 95, 339, 101, 281, 282, 283, 280, 384, 111, 114, 191, 112, 113, 358, 290) mostly along the Hudson shore and in the western valley slopes. On the Mechanicville quadrangle no outcrop was included into the Flysch Melange. Four outcrops on the Albany Quadrangle (1, 2, 16, 391) expose the Flysch Melange.

Lithology:

At a few outcrops (52, 116 east) layers rich in fossil hash (mostly shells of brachiopods and crinoid column fragments) were observed in addition to shale, siltstone and thin greywackes. A 1m * 20cm slabby block of coarse hashy limestone was collected at 52, as it was loose and the largest and shell-richest block seen. Similar fossiliferous limestone layers were found in the Eastern Exotic Melange (390, 359, 294) and at Snake Hill. Ruedemann (1901) reports a few occurrences of apparently the same lithology (at Block Island west of Peebles Island and at 119).

Justification of separation

Melange composed of only flysch lithologies is in places included into the Eastern Exotic Melange. The Flysch Melange as a unit could be still distinguished for several reasons. First, it seems likely that belts of systematic assemblages of exotic lithologies are volumetrically important in the Eastern Exotic Melange. Even in an area with only scattered outcrop one would therefore expect a sizeable percentage of outcrops to bear exotic lithologies. In the Flysch Melange belt only one outcrop displays exotic lithologies (black massive chert at 95). Second, there are long continuous sections across strike (1.7km in the area of the mouth of the Mohawk and 1.1km at 392) without observed zones of exotic material, which justify the introduction of a separated unit. Third, in the continuous Cohoes Gorge outcrop (116) the contact between exotic material-bearing melange and flysch material-bearing melange is very distinct and narrow. The distinctiveness of the contact suggested it would be useful to distinguish two lithostructural units west and east of it.

The mentioned massive black chert (95) occurs within the best defined area of the Flysch Melange, the confluence of the Mohawk into the Hudson. Only chert is exposed. It suggests that despite the arguments enumerated there may still be thin zones of exotic melange within the Flysch Melange.

Stream cut north of Rt. 2, east of Watervliet (392)

The longest section (1.1km) across strike in this unit is provided by a stream cut north of Rt. 2, east of Watervliet. It extends from behind a brick company building east of K-mart at Rt.5 in the west to where the tributary river disappears under Watervliet in the east. It is accessible from behind the brick-building, from the northern turn of a U-type street off Rt.5, and to the east from the northern rim of a little, separate, private housing-developer "village", which borders the deeply incised valley there. At the western outcrop limit the strata are strongly disrupted and some slickensided veins can be found. Towards the east, in a labyrinthic,

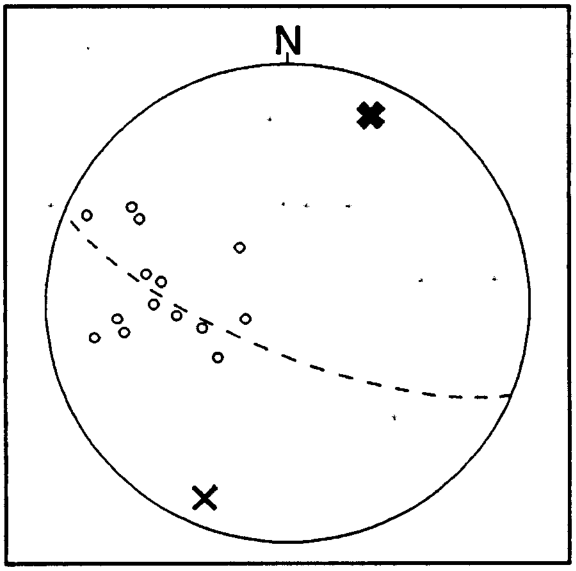


Figure 65 Stereographic projection poles to bedding planes in 392, x is poorly defined axis of rotation, x is one hinge line.

strongly meandering section, bedding becomes quickly dominant and good chevron folds with a m-scale wavelength can be observed. Attitude of bedding in the extensive bedded part varies (fig. 65). Strikes in the range from 170° to 000° are frequent, but more typical values around 020° are also present. As a whole, stereographic projection of poles of bedding defines poorly a girdle, whose pole - an average rotation axis common to all planes - trends 022° and plunges 17° to the north. A hinge line of a fold trends in about the same direction (203°) but plunges gently to the south (12°).

To the east, east of the dam at the center of the outcrop, melange and bedded zones (slices) alternate more rapidly. Farther east the shale becomes pervasively cleaved and includes minor amounts of greywacke slabs. In places, thick (4cm) slickensided veins crosscut the melangy shale.

Below the Waterford Dam (266)

Below the Waterford Dam (266), which controls the confluence of the Mohawk River into the Hudson River, a 500m long and 15m wide stripe of bedrock is nicely exposed in map view at low water (fig. 67). The outcrop provides a link between the Cohoes Gorge outcrop, which extends to the east to under the Rt.32 bridge, and the bedrock cliffs of the islands in the area between Mohawk River and Hudson River. When the water is very low, then the river beds provides nearly continuous outcrop from below the dam to Peebles Island.

0.1m to 0.5m thick greywacke beds are frequent. In the southern part bedded sections are small, mostly restricted to single greywacke beds and frequently disrupted by

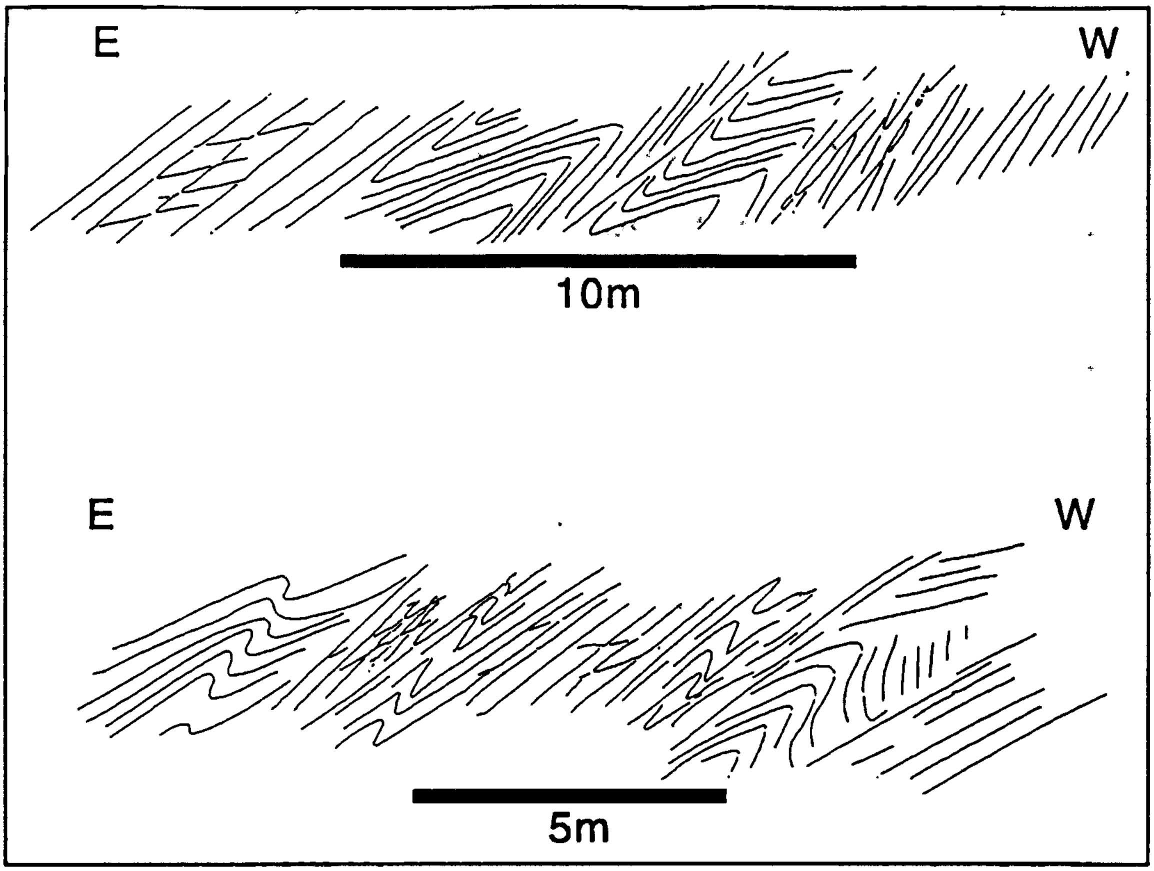


Figure 66 Two slightly generalized line drawings of chevron-type folds in bedded shale and siltstone in outcrop 392

phacoidally cleaved shale. To the north bedding becomes more recognizable and defines fold structures with apparently steeply plunging hinge lines at a length scale of 10m to m. Phacoidally cleaved shale is present in the north as well and separates larger slices of bedded material. Many instructive observations can be made. Sedimentary structures in the greywackes include nice pore-water-escape structures (fig. 68) and little slump folds (fig. 69). Pyrite sometimes crystallized abundantly and defines bedding parallel layers. Especially instructive is a small fault which changes its mode from discrete to melangy. It can be traced coming out of a bedding plane, then climbing section in the bed and turning into a 5cm broad fault zone (fig. 70), which cannibalizes surrounding shale and overprints it with a phacoidal cleavage with its average plane parallel to the shear zone boundaries.

Structure

Phacoidal cleavage is the dominant structural element. In places isoclinal folds are recognised. Good chevron folds in shales and siltstones with m-scale wavelengths occur in the west part of 392. Towards the western limit of the outcrop strata become disrupted and slickensided veining sets in. This is an example of a westward increase in deformation.

Characteristic for this unit are slices of well bedded strata (79, 266, 290, 358 west, parts of 392).

Figure 67 Outcrop below the Waterford dam [266], looking north. Peebles Island in the background (right) can be accessed, but the islands to the left not so easily.

Figure 68 Pore water escape deformed overlying greywacke and folded interbedded shale and siltstone (folds very faint due to overexposure of photograph [266].

Figure 69 Small slump folds in thin turbidites [266].

Figure 70 Phacoidally cleaved shale cuts bedding and juxtaposes two greywacke blocks. Normal fault in bottom block by cannibalizing phacoidal cleavage indicates sinistral shear sense [266].

Graptolites and age

Most of the fossil localities on Ruedemann's map of the Capital district (1930) are situated in this unit. Specific information by Ruedemann (1901,1912,1930) about graptolite contents of a number of localities is summarized in fig. 71. *Cryptolithus tesselatus* and graptolites indicative of *C. americanus* (after Riva 1974) were found by the railroad bridge between Cohoes and Waterford (see cross-section in map pocket , Riva 1983, pers. communication to Kidd), perhaps at 52. Riva (pers. communication to Kidd 1983) also found graptolites high in his *C. americanus* zone or low in the *C. ruedemanni* zone in the Flysch Melange part of 116.

On Ruedemann's map (1930) most of the Flysch Melange is included in his Snake Hill shale. However, he distinguishes three small "outliers" of other stratigraphic units within the area of the Flysch Melange. Two contain white weathering black chert according to Ruedemann and were assigned by him to his Normanskill shale. One of those is located in Waterford and includes outcrop 52 with massive black chert, the other one is described as "a small but prominent hill just west of Delaware and Hudson tracks at Watervliet, where the peculiar appearance of the rock has led to fruitless mining operations" (south of 92). The latter outcrop has apparently disappeared. The third outlier (Albany Rural Cemetery, 134) was assigned by Ruedemann (1930) due to its graptolite content including, *Glossograptus quadrimucronatus cornutus,* to his Canajoharie shale.

locality\grapt.	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
close 274	X					X										
392		X				X										
s 274, Cohoes		X				X										
300m s 339	X								X							
276									X							
79, 130	X	X									X			X		
1km e 93						X			X							
215													X			
134	X				X	X	X			X		X	X		X	X
500m se 117				X												
1.2km ese 214		X		X												
214	X															
1km east 2																
400 west 1	X				X	X			X				X			
1	X															

1*	*Diplograptus putillus*	5	*Diplograptus spinolosus*	9	*Cl typicalis*	13	*Orthograptus quadrimucronatus*
2*	*D. foliaceus*	6	*Corynoides curtus*	10	*Cl. strictus*	14	*Cryptograptus tricornis*
3*	*D. quadrimucronatus*	7	*Co calicularis*	11	*Glossograptus quadrimucronatus pertenuis*	15	*Mastigograptus circinalis*
4	*D. amplexicaulis var. pertenuis*	8	*Climacograptus caudatus*	12	*Gl. quadrimucronatus mut. cornutus*	16	*Lasiograptus eucharis*

* species is mentioned in Ruedemann (1901), but not in bulk list of Snake Hill in Ruedemann (1930); 1km east of 2 see p.502 (Ruedemann 1901)

Figure 71 Graptolite localities and contents in Flysch Melange (from Ruedemann 1901,1930). Names were copied and may have been revised.

Elam's map

Elam (1960) mapped in the Troy South portion of this unit and placed a boundary just about through the median line of the unit in the north crossing the Hudson at Albany and following it to the south. The Troy South portion of his map was redrawn and added to the map pocket. It separates conformably his western lower member of his Snake Hill Formation from the eastern upper member. The lower member is explained on his legend to consist of "grey shale and subgreywacke". The upper member of his Snake Hill Formation is composed of "silvery grey shale with large slide blocks". Judging from my observations it is very difficult to argue in this area for any conformable relations. Although it is true that at some outcrops larger conformable packages of strata are exposed, it is nowhere possible to follow a stratigraphic column for larger distances (say more than m) as ubiquitous intense deformation and monotonous lithologies effectively restrict correlation. Also the motivation for the placement of such a boundary at the chosen position is difficult to see. His thesis does not elaborate much on the definition of his units and the boundary. It just repeats the difference of the units as stated on his map, as containing or not containing blocks. Slabs and blocks in a phacoidally cleaved shale matrix can be found on both sides in the field area, however. A reason for Elam's placement may have been that on the Troy South quadrangle all occurrences of larger bedded slices (392, locally in 134) are found west of his boundary. However, on the Troy North quadrangle such slices occur also east (226, 130) to far east (290) of his projected boundary. There are no distinct changes in lithologies across the boundary in the north. South of Albany the boundary coincides with the boundary between Flysch Melange and the Frontal Exotic Melange to the east.

The area described in other publications

The State map (Fisher et al. 1970) colours all of the Flysch Melange as Canajoharie Shale. The second Normanskill outlier of Ruedemann (1930) just south of 92 is assigned to the Taconic Melange unit.

The NYS geological highway map (1990) shows Snake Hill shale in this area.

Correlation with Vollmer's units

Vollmer's (1981) lithostructural unit 6 - thick bedded greywacke and shale, locally folded and disrupted - is considered to be the southern equivalent of the Flysch Melange. It is located east of non-flysch material bearing melange and shows typically bedded strata.

Frontal Exotic Melange

East from the Flysch Melange towards the Taconic Allochthon a larger variety of lithologies including non-flysch lithologies is encountered. Outcrops are found at the Hudson River shore and in the slope from the river plain to the Taconic Highlands to the east. The following outcrops expose exclusively or partially significant amounts of non-flysch material: 336, 400 (Ryesdorph Hill), 385, 387, 337, 401, 338, 137, 100, 402, 167, 102, 169, 103-109, 284-288, 164, 277. The following outcrops expose thick greywackes as the dominating lithology: 142, 143, 147, 148, 149, 311 (bedded), 157, 158, 211, 370, 403 (bedded). There are also small well bedded shale-thin greywacke slices: in 137 west, in central 355.

The type of exotic material and its mode of occurrence differs from the exotic melanges to the west. Besides the black chert-sideritic mudstone-green shale assemblage (99, 336, 401, 337, 167), limestone conglomerate (400, fig. 72), limestone breccia (137), micritic mudstone (100) and apparently Taconic siliciclastics (100, 164, 288, 289) add to the variety of non-flysch lithologies. At 106 a hard, grey, siliceous, fine-grained sandstone is associated with massive black chert. At 164 a strong slaty cleavage adds to the exotic character of Taconic brown siltstone interbedded with dark mudstone (fig. 73). Massive black chert is found in areally extensive (up to 1.3km * 0.3km at Pleasantdale, northern Troy) coherent blocks or slices (also "Mt. Olympus" in Troy, 402, and 338), whereas chert blocks in the melanges to the west are on a m scale.

The western and eastern boundaries

The boundary between the Flysch Melange and the Frontal Exotic Melange is defined by the westernmost occurrences of exotic material in the Frontal Exotic Melange. The boundary between the Frontal Exotic Melange and the Taconic Allochthon is defined by the westernmost occurrences of Taconic lithologies in the allochthon. The Taconic lithologies were found to be easily distinguishable from the black and grey shales and dark brown weathering siltstones of the flysch.

Figure 72 Limestone conglomerate at Ryesdorph Hill [400].

Figure 73 Taconic, interbedded brown siltstone and black mudstone in Frontal Exotic Melange exhibit “exotic” narrowly spaced slaty cleavage [164].

Three contacts were observed by me. The western contact of the Pleasantdale chert ridge with phacoidally cleaved flysch is exposed at 103 at the Hudson shore and is taken as the boundary between Flysch Melange and Frontal Exotic Melange. The sharp contact juxtaposes brown, siliceous, resistant sandy siltstone (which grades farther to the east into black massive chert) on the east with grey melangy shale to the west. It strikes 000°, dipping 55°E. No textural gradients towards the contact could be observed on either side of the contact.

1.5km eastward a contact between disrupted and veined black shale and greywackes and bedded dark shale with quite frequent greenish, often channeling, quartzitic sandstone interbeds (< 15cm) is exposed (357). It is not possible to point exactly at the contact because of the similarity of the shales, but the disappearance of the quartzitic interbeds, progressive disruption, beginning of veining and appearance of greywacke slabs are very distinctive features crossing the contact from east to west. The foliations in the flysch are generally steeply east dipping. This contact is taken to be the boundary between the Frontal Exotic Melange and the Taconic Allochthon.

South of Rensselaer Polytechnic Institute (211), where the Poesten Kill gorge opens and the falls terminate into a small pond (fig. 74), the Poesten Kill offers the best exposed contact between the Taconic Allochthon and the Frontal Exotic Melange. Green-gray Taconic siltstone featuring bedding, slump folds and quartzitic channels, is separated sharply from a very chaotic greywacke-rich melange by slickensided quartz-calcite veins (fig. 75, see map "Frontal Thrust Poesten Kill" in map pocket).

Xia (1983) mapped accurately 3km along the boundary between the Taconic Allochthon and the Frontal Exotic Melange west of Oakwood Cemetery in Troy. He found a 1km * 0.1km slice of white weathering bedded chert and green highly deformed slate, which nevertheless underlies the chert conformably. He correlates those with the Mt. Merino formation and Indian River formation respectively. It is separated from Taconic rocks to the east by a 10m to 15m wide zone of "highly foliated" (Xia 1983) shale including blocks from both sides of the zone. A xerox copy of a photograph of this zone (Xia 1983, p. 83) rather shows fairly typical phacoidally cleaved shale. To the west phacoidally cleaved shale includes rare slabs of greywacke. Xia (1983) refers to the 10m to 15m wide zone east of the chert-green slate slice as the main basal thrust and provides stratigraphic and structural arguments for a thrust sense of this fault. Xia refers to the boundary between Taconic rocks and melange as basal thrust in his whole mapping area. As no independent evidence from his mapping relates to the role of this thrust for the emplacement of the allochthon, no actual meaning is attached to his use of the term "basal thrust". He includes the chert as a huge block into the melange to the west in his text, but separates it somewhat inconsistently from his Snake Hill shale to the west on his map by another thrust fault. All foliations, e.g. bedding and phacoidal cleavage, dip steeply to the east. However, the thrust west of his chert-slate slice is drawn to indicate gentle dips for the fault plane.

Figure 74 The Poesten Kill Gorge in Troy exposes the Taconic Frontal Thrust at the base of the Falls [211]. Looking east.

Figure 75 Sharply defined Taconic Frontal Thrust dips steeply east and thrusts greenish bedded siltstone with quartzite channels over greywacke block rich melange [211].

Graptolites and age

Ruedemann (1930) indicates 21 fossil localities on his map of the Capital district. Fig. 76 summarizes graptolite information from Ruedemann (1901,1930) for localities where specific information was available. *C. bicornis* occurs only in the four localities exposing massive black chert. This is consistent with correlation of these cherts with the Mt. Merino chert of the Taconic Allochthon.

At 338, a chert hill NE of the RPI Technology Park S of the Hudson Valley Community College, graptoliferous shale was found on the northern slope of the hill. The graptolites give the shale a soapy purplish stain where they are abundant. Even though most graptolites are not well preserved, a couple of thin shale slabs were collected. In the mapping area and adjacent areas graptolites are most abundant in Mt. Merino chert (Xia 1983, Lang 1969). The lithology and the abundance of graptolites indicate a correlation of the rocks exposed at 338 with the Mt. Merino chert.

A pebbly limestone conglomerate exposed at the north end of the crest on top of Ryesdorph Hill (400) is the only one of this kind observed in the mapping area. It is most likely a block in the surrounding exotic melange (336 along strike to south) as phacoidally cleaved shale containing sideritic mudstone and pale green shale exposed at places down the slope to the west of the outcrop demonstrate. Ruedemann (1930) sampled a wagon-load of pebbles (a significant portion of the outcrop !) from this conglomerate and found a long list of fossils. He writes (p. 105):

> The most interesting facts obtained were that the faunas of the pebbles range from the lower Cambrian to the Trenton, that the Chazy is represented in the pebbles, which

localities\graptolites	1	2	3	4	5	6	7	8	9	10	11	12	13
403 n (Brothers' quarry)	X		X										
403 s (Ruscher's quarry)	X												
300m e of 403 n (gully)	X		X	X									
near 100 (Poestenkill)			X	X	X	X	X	X	X	X			
402 (Mt. Olympus)								X	X		X	X	X
near 208 (Troy)	X	X											
near 385 (Rensselaer)					X								
Hudson shore,w 106,(bluff)			X					X					
near 102 (Lansingburg,. tel. power house)	X		X	X				X	X		X	X	

The bottom locality (near 102) additionally contained (Ruedemann 1901,1930): *Didymograptus serratulus, Diplograptus angustifolius, D. aff. putillus, D. whitfieldi, D. acutus, D. euglyphus* var. *pygmaeus, Climacograptus scharenbergi, C. eximius, C. modestus, Corynoides gracilis, Dicranograptus conturtus, Azygograptus? simplex*

The locality near or at 385 (corner High street and Third avenue) additionally contained (Ruedemann 1930): *Loganograptus logani, Tetragraptus quadribrachiatus*

1	*Diplograptus amplexicaulis*	4	*Diplograptus foliaceus*	7	*Dicellograptus sextans*	10	*Cryptograptus tricornis*
2	*Corynoides curtus*	5	*Leptograptus subtenuis*	8	*Climacograptus bicornis*	11	*Didymograptus tenuis*
3	*C. calicularis*	6	*Dicellograptus intortus*	9	*C. parvus*	12	*Dicranograptus ramosus*

13) *Dicranograptus contortus*

The locality descriptions in parentheses were used by Ruedemann (1901,1930).

Figure 76 Graptolites localities within the Frontal Exotic Melange (from Ruedemann 1901,1930). All 4 localities bearing black massive chert yielded *C. bicornis*, and all others did not.

is only known on the surface in northern New York and Vermont.. ..none of the groups of pebbles with their faunas can be referred to ledges of rock in eastern New York or neighboring parts of Vermont and Massachusetts, which means, in our view, that they came from rocks in the east ..

The very large age range of the carbonate pebbles from lower Cambrian to Medial Ordovician times and the exclusive occurrence of carbonate indicates an areally restricted source exposing a vertically extensive section of rocks, probably a fault scarp.

Ruedemann's map

Ruedemann (1930) assigns three units to the area occupied by the Frontal Exotic Melange: his Snake Hill shale, his Normanskill shale and his Deep Kill shale. Apparently he used mainly faunal arguments to distinguish in this area between these units because he copied essentially the boundary between Snake Hill shale and Normanskill shale from his 1901 map, on which he used only faunal assemblages to separate between units. Particularly evident is his biostratigraphic assignment of the locality near or at 385 which he first (Ruedemann 1901) assigned to his Normanskill shale and then (Ruedemann 1930), after recognition of two more graptolites, assigned to his older Deep Kill shale. All of his boundaries are essentially conformable. In my view the variety of age assignments reflects the chaotic nature of the melange including blocks and slices of various ages. It is not possible to establish a stratigraphic column within the Frontal Exotic Melange.

Elam's map

Elam (1960) outlines several thrust bounded slices east of the Hudson River in the area of the Frontal Exotic Melange, which were, according to his map, pushed over the essentially autochthonous upper member of his Snake Hill Formation consisting of "silvery grey shale with large slide blocks". His upper member of the Snake Hill Formation occupies a ENE trending, narrow strip along the Hudson on the north part of the Troy South Quadrangle and swings to a north-south direction in the south part of the Troy South Quadrangle. To the east it is juxtaposed with a long continuous thrust slice of his lower member of the Snake Hill Formation along most of its length. Just north of Rensselaer the juxtaposing thrust cuts for a small distance through his Austin Glen member of the Normanskill Formation, which is drawn to conformably underlie the Snake Hill at this position.

To the east another thrust separates his Snake Hill slice from a structurally overlying slice of his Austin Glen member of the Normanskill Formation in much of his field area. The chert hill NE of the Technology Park (338) is included in this unit. It is coloured as Mt. Merino member of the Normanskill Formation and interpreted to be the core of an anticline conformably overlain by his Austin Glen member. East of his Austin Glen slice another thrust separates this slice from Taconic rocks.

From my mapping I locate the position of the boundary between Taconic rocks and flysch at the same position as Elam (1960) does. Also, the Frontal Exotic Melange contains certainly enough deformation to be consistent with thrusting under the Taconic thrust sheet, which is what Elam (1960) claims.

However, in detail my mapping cannot confirm Elam's work. Lithologic differences were not found to be distinct and consistent enough to propose subdivisions of long continuous belts. This is indicated even by Elam's map if one takes into account that his "large slide blocks" in his upper member of the Snake Hill Formation, his small occurrence of the Austin Glen member of the Normanskill Formation or his chert at the core of an anticline (338) in the Austin Glen slice represent in the field essentially blocks in phacoidally cleaved shale matrix. Also, outcrops located in his Snake Hill slice, which he describes as containing "grey shale and subgreywacke", expose locally block-in-matrix textures (100, 135, 137, 138, 401) or thick, bedded greywackes similar to the Austin Glen member of the Normanskill Formation (403). From my observations I believe that slice dimensions are much smaller. If one uses preserved bedding as the slice defining element, the maximum width observed in the Frontal Exotic Melange is about 15 m (403). If one uses a characteristic lithology as the slice defining element, the maximum width observed is about Elam's width of 0.7km in the area between Rosemont Park and Defreestville where thick, massive and coarse greywackes are exposed in a peculiar cluster of outcrops (142, 143, 145, 147, 148, 149). This cannot be traced further along strike because of lack of outcrop. Still, this occurrence, and thick, bedded greywackes at the west side (311) of the Technology Park chert hill, and greywacke rich melanges just south of Burdens Pond (157, 158) and at the Poestenkill (211) make his Austin Glen slice the best defined one. On the other hand, the mentioned outcrops are not necessarily connected in one continuous slice.

The State map

The State map (Fisher et al. 1970) separates within the Frontal Exotic melange several occurrences of its Taconic Melange unit, Austin Glen greywacke unit, and Mt.

Merino chert unit. The Technology Park chert hill (338) is identified as Mt. Merino chert. The cluster of outcrops exposing dominantly thick, massive greywackes and Elam's small occurrence of his Austin Glen member of the Normanskill Formation below his lower member of his Snake Hill Formation are identified as Austin Glen greywacke. The north part of Elam's upper member of his Snake Hill Formation east of the Hudson and areas surrounding Ruedemann's Mt. Olympus (402) and Ryesdorph Hill (400) are identified as Taconic Melange. It seems that in this area the state map is essentially an outcrop map indicating lithologies of single outcrops. Boundaries separating these units from the surrounding Canajoharie shale are essentially outcrop boundaries. The map fails to show the largest occurrence of massive chert at Pleasantdale (102-109, 284-287).

The NYS Geological Highway (1990) includes all of the Frontal Exotic Melange into its Snake Hill shale.

PAGES BETWEEN 137-142 AND 145 -149 ARE NOT MISSING
THEY ARE JUST NUMBERED INCORRECTLY

Sedimentology

The majority of sediments in the field area can be classified as flysch. There is a small, but interesting amount of other non-flysch sediments as well.

Flysch sediments

The term "flysch" was referred to as "one of the most used and abused words in geology" (Mitchell and Reading 1986). It is not well defined (Hsü 1970), but typically refers to a thick succession of syntectonic deep-water sediments, such as shales, marls and turbidites. Therefore it is not only customary for this belt (Hiscott et al. 1986, Bird and Dewey 1970, Rowley and Kidd 1981), but also sensible to call the black shale, grey shale, siltstone, thin, fine-grained greywackes and medium-grained thick greywackes in the field area "flysch".

Turbidites

From a sedimentological point of view the various greywacke turbidites within the field area attract most attention. Kuenen's student Bouma (1962) recognized the characteristics of a typical greywacke deposited by a turbidity current. He established a sequence of sedimentary structures from the base to the top of a typical turbidite bed. Subsequent work (Kuenen 1967, Mutti and Ricci Lucchi 1972) confirmed and refined turbidite classification. Krueger (1963), Middleton (1965), and Fagan and Edwards (1969) studied turbidites in the field area and south of it.

Many greywacke beds in the field area show some characteristics of turbidites such as graded bedding, bottom marks indicating flow, convolute laminations and dish structures, but only a few show a complete sequence of sedimentary structures in one bed.

Paleo-Current Directions

Linear features (flute and groove casts) at the undersides of turbidite beds enable one to recognize the orientation of flow and sometimes also its direction. Middleton (1965) and Vollmer (1981) measured such linear features in the field area and closeby, Krueger (1963) just west of it. To the south, south of Catskill between North Germantown and Saugerties, Fagan and Edwards (1969) repeated this routine. Krueger (1963) shows that the main flow direction is mainly to the north or northeast; Middleton's (1965) main flow direction is also to the northeast; Vollmer's (1981) data show north-south flow in both directions and Fagan and Edwards (1969) report discernable maxima of paleo-current directions to the northwest and northeast. Fagan and Edwards (1969) add also the observation that current direction can gradually rotate to a high degree with age in one continuous section of an outcrop. Middleton (1965) did not correct his direction data for tectonic rotation, whereas Vollmer (1981) and Fagan and Edwards (1969) took tectonic rotation into account by strike correction when they sampled and plotted their directions. These results show that sand transport occurred in a broad sense longitudinally, in the elongate north-south flysch basin, but that widely divergent directions occurred at times.

I did not measure the orientation of sole markings systematically. They occur mostly on thick greywacke beds, but are even on these more an exception than the rule. The area where they are most frequently observed is the southern HGZ.

Shallow-water environment versus deep-water environment

Frequent low amplitude/high wave-length crossbedding in the field area led some previous workers (Ruedemann 1930, Rickard and Fisher 1973) to infer an origin in shallow water above the wave base for those crossbedded greywackes. Crossbedding can be explained also, and more consistently with the other observed sedimentary features, lithologic associations, and tectonic setting, by a deep-water origin as a result of deep trench parallel bottom currents. Small-scale cross-laminations are frequent in the upper part of deep-water turbidite beds and form part of the standard Bouma sequence (Howell and Normark 1982). Cross-laminations observed in graded beds showing bottom marks therefore actually confirms a turbidite origin, which are considered to be typical deep water sediments. Other sedimentary structures include convolute bedding, dish structures formed by pore-water-escape and deforming in places cross-bedding, and small slump folds.

Many greywacke beds are entirely cross-bedded, but on a small scale and usually in the form of multiple sets of climbing ripples. Some largely crossbedded layers show scour by those into typical turbidites. This relationship indicates strong bottom currents in deep water, which redistributed sands originally delivered by turbidites. In an area where both crossbedding by reworking and sole markings by turbid flow can be found, it may be interesting to determine wether the two structures indicate distinguishable sets suggests reworking of turbidites by bottom currents, probably trench parallel along the axis of the basin.

Origin of non-flysch lithologies

Fig. 68 gives a list of observed non-flysch lithologies. The fact that they occur in a systematic assemblage makes it possible to infer paleogeographic sites of original deposition more specifically because a depositional model must integrate depositional environments of single lithologies in a consistent manner. The original site of deposition of the non-flysch lithologies is inferred to be the slope and rise or basin plain of a carbonate-dominated continental margin.

Massive, Black Chert

The most abundant block lithology is massive black chert. Bedded chert is commonly thought to be a product of radiolarian ooze deposited in a quiet, pelagic setting, away from siliciclastic sources (e.g. Jenkyns 1978). A thin section of a chert sample of Rt.7 shows layers of small spheres, which are probably radiolaria. Litho- and biostratigraphically the black, massive chert can be identified as Mt. Merino Formation (Rowley et al. 1979). Ruedemann (1942) and Lang (1969) describe radiolaria from the equivalent Mt. Merino chert within the Taconic allochthon. Lang (1969) suggested that the dominant source of silica for the construction of the black chert either by direct precipitation at the sediment-water interface or by indirect deposition via radiolaria was volcanism as indicated by the presence of small amounts of augite, hypersthene and hornblende fragments. This could not be confirmed in my thin sections. The massive black chert is inferred to be derived from a continental rise or basin plain position.

Pale Green Shale

The depositional environment of green pale shale, always present in the exotic melange, is not well constrained. It is tempting to correlate the pale green shale with the red and bluish-green slates of the Indian River Formation (Rowley et al. 1979), which underlie the Mt. Merino chert. Two observations tentatively suggest this correlation: First, Rowley (1983) mentions pale green, pale greenish-gray, and gray slates that are locally developed near the top of the unit. This occurrence helps to reconcile the color discrepancy in that it is conceivable to assign this lithology near the top a greater importance in the area where the pale green shale of the exotic melange originally came from. Rowley (1983) also mentions that at some locations the entire thickness of the Indian River is pale green or pale gray-green. Second, an extensive outcrop just north of Catskill along Rt. 9W (area of company "Village Oil") in exotic melange, which displays heavily disrupted massive chert, also yielded minor amounts of green siliceous shale displaying small, reflecting, sand-sized particles dispersed on fracture surfaces. This property is also described from the Indian River (Rowley 1983). If the correlation holds, then the position of the Indian River in the stratigraphic column can be utilized to infer deposition in a rise environment (Rowley and Kidd 1981), possibly closer to a terrigenous source than the Mt. Merino chert.

Laminated, Sideritic Mudstone

Brown-red weathering laminated sideritic mudstones barren of macrofossils and similar lithologies occur regularly in the exotic melange. Similar lithologies are not found in the Taconic allochthon; sideritic rocks near Mt. Tom (Hofmann 1986) are coarse quartzose sands and breccias. This lithology is also interpreted to have been deposited in a pelagic environment as a deep water carbonate. In the allochthon, Mt. Merino chert is overlain by flysch (Rowley and Kidd 1981). Therefore it is likely that the laminated sideritic mudstones are older or of the same age as the chert, because after initiation of flysch deposition the depositional environment would have been unsuitable to deep water carbonate deposition. The occurrence of chert and pelagic carbonate indicate spatial or temporal variations of depth of deposition. Spatially, there may have been a rise or basin plain topography which allowed for both, chert and carbonate deposition. Carbonate would have been deposited upslope at the lower slope of a carbonate-dominated shelf or above an intrabasinal plateau. Temporally, there may have been a successive deepening of the basin, which restricted carbonate deposition after the basin floor and enabled chert deposition. Then, the laminated sideritic mudstone would be the equivalent to the hemipelagic Indian River or pale green shale, and the massive black chert perhaps a more seaward equivalent of the Mt. Merino chert. Given the rarity of exposed non-flysch material and total lack of direct stratigraphic or lateral facies control, these conclusions are highly speculative and preliminary.

Carbonate Breccia and Conglomerate

Various kinds of carbonate breccia in the Cohoes Gorge outcrop and the carbonate conglomerate at Ryesdorph Hill (400) are thought to have been deposited at the slope of a carbonate-dominated continental margin. Talus breccias and debris flow deposits are common in fore-reef slopes and other steeper carbonate slopes (Enos and Moore 1983, Cook and Mullins 1983). Clasts in the carbonate breccias are in general fossiliferous, indicating derivation from a shallower carbonate platform. The faunal content of the cm-sized clasts in the Ryesdorph Hill conglomerate show a large age range from Cambrian to Medial Ordovician (Ruedemann 1930). The large age range requires an extensive sum of total vertical exposure of platform carbonates in a restricted source area. Steep to near vertical escarpments at reef margins are known from modern shelves and can exceed several hundreds of meters in height (Enos and Moore 1983). Faults scarps along active faults provide another depositional environment for such breccias. Large scale lystric normal faulting with the appropriate displacement and accompanying talus breccias are recognized in the Mohawk Valley (Bradley and Kidd 1991). The formation of the carbonate breccia, now visible in the melange, therefore is most likely associated with similar faults.

Other non-flysch lithologies are too rare to warrant a meaningful contribution to the origin of the assemblage of non-flysch lithologies and are not further discussed.

Depositional environment

It is possible to interpret the depositional environment of the non-flysch lithologies in a consistent manner as ranging from rise to lower and upper slope of a carbonate dominated continental margin. The siliciclastics of the Taconic allochthon fit also the characteristics of deposition in a slope/rise environment of a continental margin, e.g. the passive margin of former North America (Bird and Dewey 1970, Rowley and Kidd 1981). The occurrence of carbonate breccia and laminated, sideritic mudstone may indicate a generally more continentward original depositional site as compared to the Taconic allochthon.

STRUCTURE AND LOCAL IMPLICATIONS

The structures observed in the field area are described from a domain scale to an outcrop scale in the previous chapters. This chapter covers more general topics and implications. The idea of imbricate thrusts as the controlling structural element in the field area is introduced and evidence for it is discussed. Then, the origin of the melange, the phacoidal cleavage within it and its relation to slickensided veining are discussed from both the published literature and from field relations. Finally, a structural history is proposed and summarized in a schematic cross-section.

Imbricate Thrusting

Cross-sections of the deformed foreland in the Canadian Appalachians (St. Julien et al. 1983) and generally from foreland basins (e.g., Canadian Rockies, Fermor and Moffat 1992) show typically a long, gently dipping detachment surface and splays reaching from the detachment to the free surface (see also Boyer and Elliot 1982). Dips are toward the orogen. Cross-sections like those are constructed from careful geologic observations and indicate the following processes. At times the detachment abandons its tip reaching from the basal plane towards the surface and builds out in the thrust direction by addition of a new gently dipping part and upwards steeping of the thrust surface to include an additional slice. This way a whole stack of thrust slices develops and the foreland is imbricated (fig. 77). The normal time sequence of thrusting is from the interior to the exterior with the youngest faulting at the tip of the detachment and far travelled

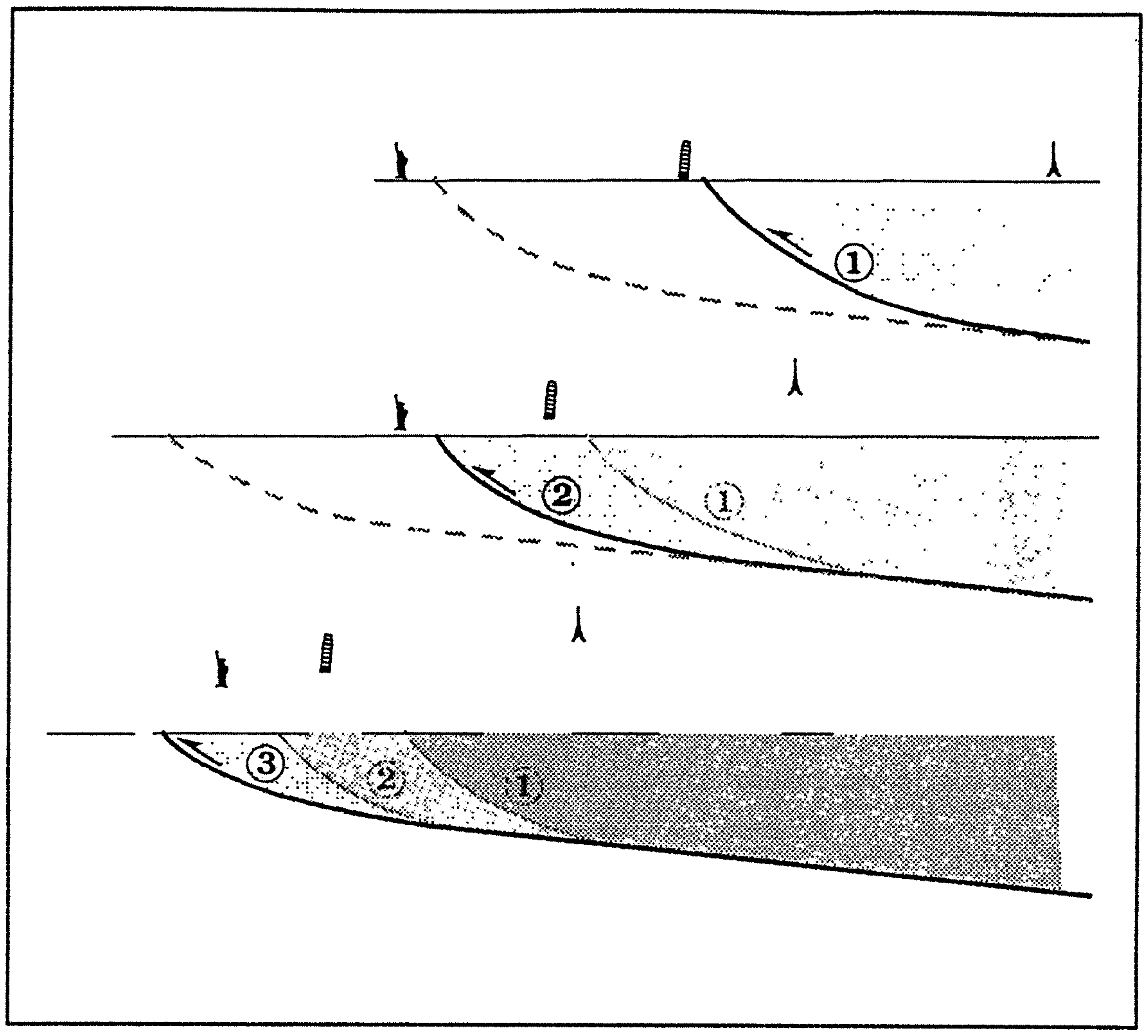


Figure 77 Diagram illustrates imbrication by progressive thrusting. Markers show different amount of horizontal and vertical offset. Initial distance between surface traces of thrusts becomes shorter due to the gentle dip of the detachment. Darker shading indicates higher amount of transport. Lighter stippled lines indicate positions of incipient thrusting, that is the subsequent location of the active detachment.

slices overlying less far travelled slices. Often older thrusts in the allochthon are reactivated or new thrusts develop above the main detachment together with the detachment progression. The timing of these faults is "out of the sequence" of normal thrust stacking and these out-of-sequence thrusts modify older structures. The active detachment near the surface may be organized into a thrust network. Also, there may be back-rotation and steepening of older thrusts caused by the curvature of the outward building detachment. Additionally, the time span of the processes of abandoning old thrusts and initiating new thrusts may be significant compared to the whole history of shortening. Then there is a continuum of active faults with a velocity gradient toward a maximum at the frontal surface trace of the detachment fault. Shortening by thrusting may be accompanied by varying amounts of layer-parallel shortening and shortening by buckling. Imbrication on a smaller scale may results in a stack of horses (a duplex) between a sole thrust (progressing fault) and a roof thrust (instead of a free surface). There is also the possibility of plucked horses and thrust slivers which are picked up and transported with a thrust but under it. Finally, cessation of syntectonic sedimentation as the thrust stack overrides the trench may help in recording the timing of stages of progressive thrusting.

Some of these general properties of imbricate thrust systems are also recognized in the Taconics and in the field area. The question, to which extent such a model is inferred from the geology and to which extent such a model is applied to explain geology in a consistent manner is probably mostly of philosophical value. It seems that most geologists, including me, are satisfied if they can find a model which is consistent with their observations, generally accepted and able to produce testable predictions (and thereby sometimes overlooking other possible models). More interesting is how strongly knowledge (of such a model) influences observations and first-order conclusions. I do not think it is possible to observe rocks in a perfectly objective and unbiased way. This is maybe a reason why changes in thinking about a certain problem arguably occur often in an evolutionary, not revolutionary way. It is, however, imperative to be as open minded and exact in observations as possible. It can have far reaching consequences, for example, to stuff every chaotic rock in the category olistostrome. Following this train of thought, the thesis was organized in a way that separates "objective" description of lithostructural units from my inferences regarding the structure and tectonic history of the field area.

Detailed field mapping in the Taconics and the foreland in the last 15 years (Jacobi 1977, Rowley 1983, Bosworth 1980, Steinhardt 1984, Bierbrauer 1990, Herrmann 1992) could decipher many of the elements of the imbricate thrust system and establish a history of its evolution. A summary of the parts of this evolution which are relevant to the geology of the field area is given below. One result may be stated now. The location of the trace of the detachment was doubtful. This poses immediately the principal problem of how to interpret the obviously highly deformed rocks in the field area:

- as a sort of proto-thrust zone in front of a detachment
- as a result of deformation under a low angle detachment
- as a result of deformation above a detachment that outcrops further to the west

This problem is addressed by my field work.

Structural framework from previous work

Rowley and Kidd (1981) outlined the tectonic evolution of the Taconic orogeny (see TECTONIC SETTING) and demonstrated a large scale east to west progression of deformation and thrusting by means of stratigraphic relationships and provenance analysis of syntectonic flysch. In detail, they found that it is likely that a late set of thrusts imbricated the slope-rise sequence emplaced on the carbonate shelf using probably the same detachment surface at depth as the original emplacement thrust. This late set of faults is often decorated with carbonate slivers derived from carbonate attached to the detachment thrust after it was picked up during transport over the shelf edge. Presumably, this set of thrusts could be called an out-of-sequence imbricate fan. From their argument, Rowley and Kidd (1981) were not concerned with the present-day position of the detachment, but their map implies the western limit of the Taconic Allochthon, which is the eastern limit of my field area and the Taconic Frontal Thrust of Bosworth et al. (1988), as the position of the detachment.

Bosworth et al. (1988) showed that the Taconic Frontal Thrust is really a part of the (same?) carbonate-decorated, post-obduction age set of thrusts, which they termed the Frontal Thrust System. They found the following characteristics of faults of this thrust system:

- They are late, because they cut through the regional slaty cleavage in Taconic rocks and flysch and through all folds, but they are not folded themselves.
- They may be marked by melange zones

- They may be decorated with horses of shelf carbonate or by imbricate stacks and duplexes of carbonate interleaved with flysch and melange

They derived those characteristics from careful observations on key exposures of the Taconic Frontal Thrust and thrusts a short distance west of it (Steinhardt 1983), which are located to the north of the field area. The occurrence of faults belonging to this thrust system west of the Taconic Frontal Thrust is significant, because it suggests that the Frontal Thrust is not the trace of the detachment surface, which should be the westernmost thrust in an imbricate thrust system with an east to west stacking order. Bosworth et al. (1988) also tentatively identified melange zones further west as thrusts belonging to the imbricate thrust system south of their main study area and in my field area. They do not explicitly state the problem of the location of the detachment. As described above melange occurs as far as 11km across strike to the west of the Taconic Frontal Thrust.

In summary, previous work shows that shortening was accomplished by a large scale east to west progression of thrusting and identified a late, post-obduction imbricate thrust system. Identified thrusts and tentatively localized melange zones west of the previously assumed position of the surface trace of the main detachment thrust suggested a more westward position of the detachment thrust, but its position remained doubtful.

In the following the results of my field work are put into the outlined structural context as it was worked out by recent investigations.

The field area in the context of the previously derived structural framework

The following main results of my mapping need to be integrated in the structural framework as briefly outlined above. They are stated here and are based on description of the lithostructural units above.

- it is possible to identify more or less well defined, long, and continuous lithostructural belts parallel to the local strike
- cleavage and bedding is moderately to steeply east dipping
- there are extensive melange zones
- bedded slices are elongate along strike
- melange zones and bedded slices are alternating
- a well defined assemblage of non-flysch lithologies of slope-rise affinity contributes significantly to some melange zones
- west of the belts with major melange zones, there is a belt of deformed flysch with only incipient melanges and without non-flysch lithologies, west of which there is undeformed flysch

These results can be best integrated by a model which involves a location of the main detachment at the belt of the Western Exotic Melange and intense imbricate thrusting in the eastern half of the field area. In the following the relevance of the results for this model is explained and the location of the detachment and other principal explanations for deformation west of the limit of the Taconic Allochthon as stated above discussed.

The existence of long lithostructural belts parallel to the regional strike suggests separation of those by major faults. The alternative explanation, separation by essentially sedimentary contacts, is less likely in view of the tectonically dominated origin of the melange (see below). Also the belt nature of the units being long parallel bands argues strongly against essentially sedimentary contacts because the obviously intense deformation is likely to disturb any original sedimentary contacts in a less orderly manner. In comparison, separation by major faults explains much better the belt nature, because major faults are typically long and straight and often parallel. Therefore, the contacts between the lithostructural units are thought to be defined by major faults. The most eastern major fault in the field area is then the Taconic Frontal Thrust of Bosworth et al. (1988), and the most western fault the boundary between the flatlying Undeformed Flysch and the Deformed Flysch. The outcrop density does not allow for determination of qualitative dip angles of those faults. Also, their sense of displacement, normal or thrust sense, cannot be determined just from the geometry of the arrangement of lithostructural units. However, in order to integrate the results into the tectonic framework assembled from previous studies it is only reasonable to include these faults in the Taconic Frontal Thrust System as major thrusts.

Another result of the field work relates to the attitude of foliations. Three main kinds were observed: phacoidal cleavage, where the anastomosing cleavage defines an average plane; bedding; and planar veins. The attitude of planar veins did not follow an obvious general trend. They are only rarely horizontal and often vertical or moderately east-dipping, but there are also west, south and north dips. Phacoidal cleavage in the melange and bedding in bedded slices, the HGZ and the Deformed Flysch is generally moderately to steeply east dipping and only rarely gently east dipping. An exception are outcrops along Ballston Creek, where bedding is mostly gently dipping to horizontal. Phacoidal cleavage is always moderately to steeply east dipping and never west dipping. West dips of bedding were seen only at two outcrops (39, 30). The general steepness of foliation is utilized to infer the orientation of major faults or shear zones. Two cases may be distinguished. The foliations are at an angle to the shear zone boundary or they are parallel to the shear zone boundary. In the first case, the phacoidal cleavage is interpreted to be a S-type foliation in a shear zone, in the second case it is parallel to the shear zone boundary. In the first case the shear zone boundary would have a gentler dip. On a small scale, where contacts between phacoidally cleaved shale and bedded flysch were observed, no notable difference in attitude of phacoidal cleavage and the often transitional contact were recognized. This is also true for the only sharp contact between phacoidal cleavage and bedded material observed (103) and for most of the numerous slabby greywacke blocks which often have a long axis parallel to the trace of the phacoidal cleavage. Therefore the moderate to steep dips of foliations probably reflect the dips of the faults. The parallelism may be caused either by rotation under progressive shear or may have been a genuine feature of the phacoidal cleavage from the beginning of its formation on.

Another result of the field work is the recognition of the abundance of often thick melange zones east of the deformed, but bedded flysch unit. This is consistent with the observation that bedded slices are small and mostly traceable for only small distances. The second observation confirms the first, but does not add new information. It is hard to estimate the relative abundance of bedded material and melange, but in order give some idea my impression after visiting many outcrops is that in the eastern part of the field area (east of the Deformed Flysch) at least 50% of the volume of rocks is melange (that includes block-in-matrix melange, flysch melange and melangy shale). This abundance has two implications for faulting in this area (if melange zones represent fault zones, an assumption which follows from the previous discussion and which is addressed in more detail under a separate heading). Thrusts are numerous and/or often of substantial thickness as compared to the thickness of the bedded slices. These implications are related to a problem, which arises when faults become thicker by including surrounding material to a point where they are thicker than the remaining transported material or even join another fault. It then becomes difficult to separate faults and to properly distinguish between them. Additionally, lenses within shear zones may have experienced only little strain and may then be confused with small, but proper slices separated by fault zones. As the lens has another strain history and is likely to have been transported less far than the overlying slice, it is important to distinguish these cases. The origin of the thickness of the melanges is addressed later. In summary, the occurrence of extensive melanges in the eastern half of the field area indicates narrowly spaced faulting by thick fault zones. The spacing is defined by the structural thickness of bedded slices and is usually on a m-scale.

Another general result of the field work is that these bedded slices are elongate along strike. This strong correlation between the orientation of the long axis of the exposed slices and the regional strike defined by the strike of foliations suggests that both directions have the same origin. As the regional strike is a structural feature which results from deformation of the area, the shape of the slices is thought to indicate a tectonic origin of the slices. The relation between the slice shape and its tectonic origin may not be a direct one, for example, older parallel structures may have influenced sedimentation in a way so that elongate sedimentary bodies resulted. Lower slope basins with sedimentary contacts between basin fill and basement (melange) (fig. 78D) belong to this category. Such basins have been observed, for example, in the Ordovician of the Appalachians in Quebec (Castle Brook location, Kidd, pers. communication) and in Pennsylvania (Lash 1990) and in an emerged Neogen trench-slope at Nias island, Indonesia (Moore et al. 1979). The distinct Halfmoon Greywacke body in the melange-dominated eastern part of the field area is a candidate for a small lower slope basin. Unfortunately the critical western contact of the HGZ with the Western Exotic Melange is not exposed. Fig. 78 shows alternative explanations for the occurrence of the Halfmoon Greywacke Zone with its bedded greywackes within broad melange zone. Fig. 78A shows the HGZ as an outlier from the Taconic Allochthon, the interpretation chosen for State map (Fisher et al. 1970). This is unlikely because the the material in the HGZ does not have any affinity with the material just above the Taconic Frontal Thrust to the east (Elam 1960) and because no indication of folding of the Taconic Frontal Thrust could be found in compiling the central Hudson Valley. Fig. 78B shows the HGZ as a large block in melange. This is a more plausible interpretation since there are many greywacke blocks in the melange. It is important to distinguish between blocks, which are part of melange shear zones, and slices (fig. 78C), which were transported by those shear zones. I prefer to interprete large bedded units as the HGZ within the melange as slices because of their structural thickness which is larger or comparable to the thickest melange zones without bedded units and the observed lack of grading in block size from smaller (<3m) blocks,

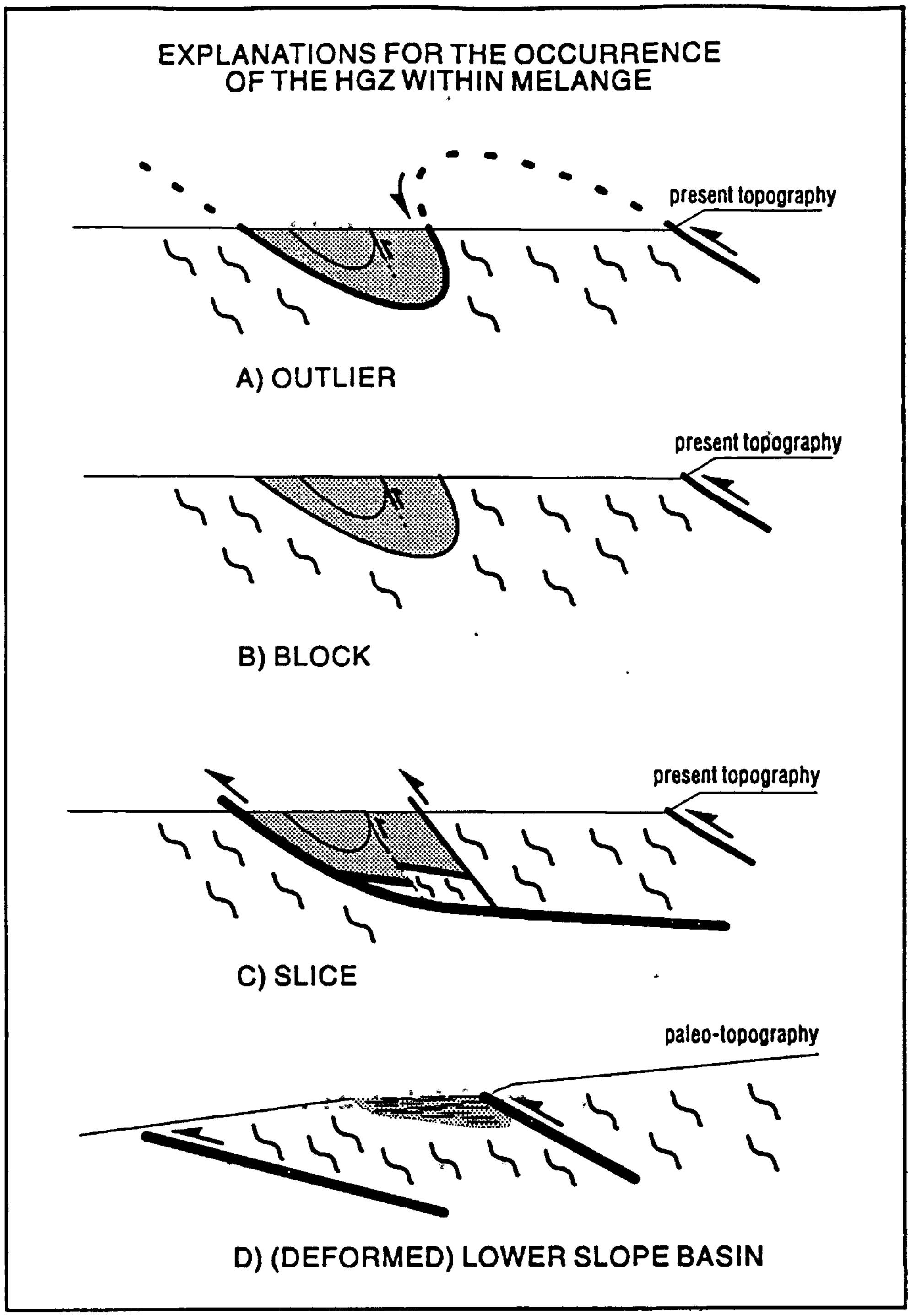


Figure 78 Four ways to place large bedded units such as the HGZ in melange. For brief discussion see text.

which are clearly recognizable as such, to blocks a few km in size, which the HGZ would represent, in outcrops of suitable size (Cohoes Gorge). Fig. 78D shows the HGZ as a still undeformed lower slope basin. This interpretation would involve an indirect relation between elongate slice shape and its tectonic origin. It is felt that there is not sufficient information to reconstruct a possible indirect relation. Therefore the simplest relation between the shape of bedded slices and their tectonic origin is preferred, in other words the same deformation which is responsible for the regional strike created the shape of the bedded slices. The bedded slices, including the HGZ, are therefore thought to be thrust slivers and slices. This argument is similar to the argument explaining the nature of lithostructural units as belts, but applied to a smaller scale.

Sufficiently large outcrops show that, in general, bedded slices and melange zones are alternating. This is also true in other scales. It is obvious for small slices and bedded blocks which are surrounded by melange shale. Also, the HGZ, the Bedded Shale unit (SSZ) and the northern Folded Thick Greywacke unit (Rocky Tucks) have melange to both the east and the west sides. This alternation argues against a successive increase in deformation from west to east. The strong contrast in melange abundance between the western half (Undeformed Flysch and Deformed Flysch) and the eastern half (from the Western Exotic Melange to the east) also has a step character, as demonstrated by the K-C-Canary outcrop (66), arguing against a gradual increase in deformation in the scale of the units in the field area. The alternating character of melange zones and bedded slices is incompatible with Vollmer's (1981) hypothesis of an overall west to east increase in deformation, which could be interpreted as the "frozen" state of a temporal evolution of deformation. Vollmer's idea may still be applicable on a small scale, to infer from transitional contacts between melange and bedded material the temporal process of melange formation, but, in general, results of my field work cannot support Vollmer's suggestion. Therefore there is a need for a revised model of melange formation, which is addressed later. The alternating nature of melange zones and bedded slices is consistent with a model in which faults are expressed as melange zones.

It was possible to recognize in some melange zones a characteristic assemblage of non-flysch lithologies, which were most likely deposited in a slope/rise environment. The massive black chert in these melange zones is equivalent to the Mt. Merino chert which occurs in its stratigraphic position in intact sections within the Taconic Allochthon, for example at its type locality at Mt. Merino near Catskill. This observation has some significant implications. First it is important to recognize that the non-flysch lithologies must have travelled a long distance from their original place of deposition to their position today above shelf carbonates. The site of original deposition was at the slope and rise of the continental margin, as indicated by the facies of the non-flysch lithologies and, even more convincingly, by the occurrence of Mt. Merino chert, whose paleogeographic and temporal position is well constrained in the Taconic Allochthon due to the more or less complete and intact stratigraphic sections in the Allochthon, of which it is part (Rowley and Kidd 1981). Now these slope/rise sediments are located far west of known occurrences of shelf carbonate, for example east of the eastern limit of the Taconic Allochthon in the Vermont Valley (Herrmann 1992). Therefore these non-flysch lithologies must have been transported a long distance and the question of the mode of their emplacement arises. Here the significance of their occurrence in non-random assemblages in certain zones comes into play.

Two ways of their emplacement west of the Taconic Allochthon may be distinguished, emplacement directly from their original site at the slope/rise, and secondary emplacement from the already transported Taconic Allochthon as a source. The first scenario suggests a fairly early establishment of the relative arrangement of non-flysch lithologies in the field area and Taconic Allochthon, early in terms of the accretion history. The second scenario has the advantage that it can explain most of the transport of these rocks as transported with the Taconic Allochthon, the emplacement history of which is well known (Rowley and Kidd 1981). The second scenario has, however, the difficulty to find a way to transport the non-flysch lithologies from the emplaced allochthon further to the west with interleaving flysch between the further transported material and the Taconic Allochthon. This further transport could occur tectonically or by sedimentary processes. In order to emplace this material tectonically from the Taconic Allochthon with imbricate thrusts of the Taconic Frontal Thrust system the material must have been brought up within supposedly broad thrusts, which requires an implausible velocity profile across the thrust. With respect to the foreland the material within the thrust must be faster than the flysch between the thrust and the allochthon. The material in the thrust would be pressed or injected into the flysch, while the flysch is transported over autochthonous flysch to the west (fig. 79). This seems mechanically unlikely in an imbricate thrust setting. In order to transport this material by sediment transport, for example by mass wasting, one expects a random distribution of the non-flysch material in the flysch and a spatial gradient in abundance of this material towards the allochthon. Neither the random distribution nor the spatial gradient are observed. Therefore the first scenario of an early arrangement is preferred. This scenario can better explain the

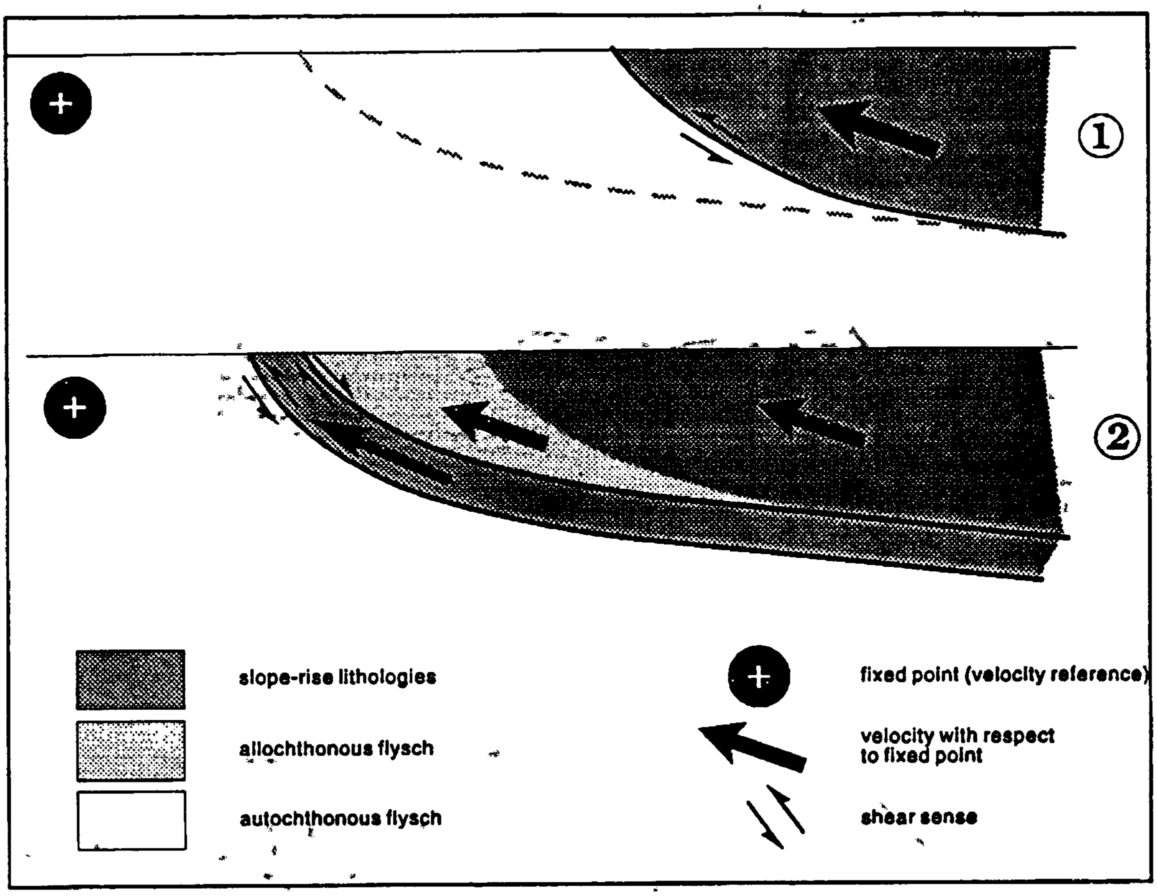


Figure 79 The sketch shows conceptually how to transport tectonically slope/rise material from an emplaced Taconic Allochthon (dark grey) to the west. Material within the fault zone must move faster than overlying, transported flysch. Some pressing action or injection is required. This scenario is mechanically implausible.

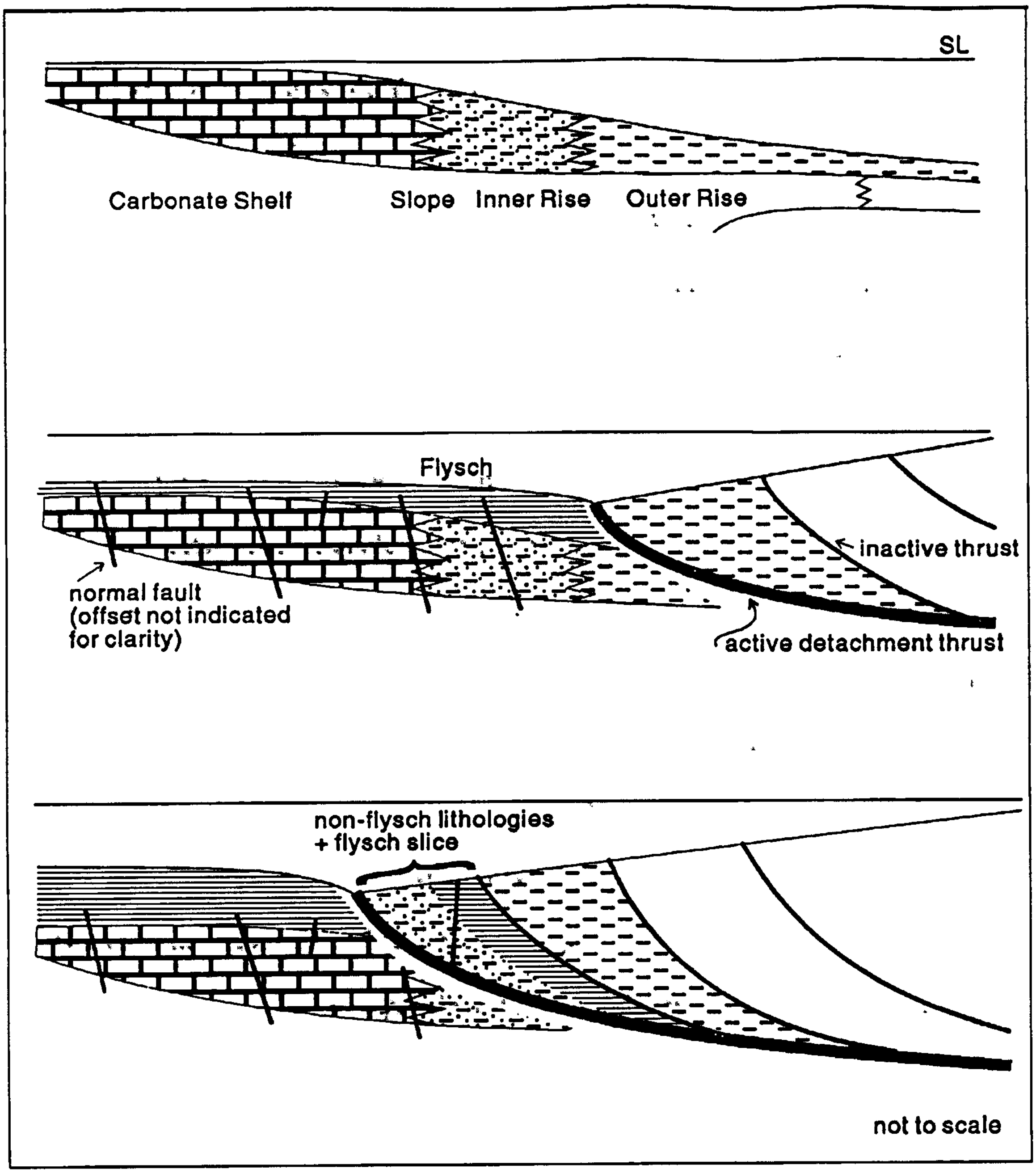


Figure 80 Initial assemblage of allochthonous non-flysch lithologies and allochthonous flysch early in the emplacement history as a continuous slice. Tectonization and melange formation occurred later (not shown on this diagram) during further emplacement and late imbrication.

occurrence of systematic assemblages of non-flysch lithologies in melange zones. In this scenario these assemblages are thought to be formerly continuous slices which were attached to the front of the detached, but little transported slope/rise section of the Taconic Allochthon (fig. 80). Melange formation occurred by later tectonization at a position close to the detachment thrust. In this scenario the flysch which now accompanies the non-flysch lithologies in the melange could have been part of the early slices in front of the allochthon or be younger flysch deposited on the shelf. In the shelf case the flysch would have been picked up later by the detachment thrust under the moving imbricate fan of assembled slices. The occurrence of good exotic melange at K-C-Canary west of extensive flysch sections argues against such a origin of the flysch if one finds it unattractive to invoke again some kind of pressing action or injection as the major emplacement mechanism for this exotic melange. Whereas such a mechanism seems unsuitable to explain the principal way of emplacement of non-flysch lithologies and flysch, it may provide a way to include younger flysch, originally deposited on a more westward position above the shelf, in a melange and above non-flysch lithologies. The "injection" is kinematically equivalent to a top-down sense of movement at the detachment (see fig. 81). Low-angle normal faulting at the detachment could move young flysch at times of relaxation above the detachment down and eastwards over non-flysch lithologies. The normal faults are required to cut through young western flysch, the detachment and allochthonous non-flysch lithologies. They have therefore a gentler dip than the detachment. This way originally more eastward located material (non-flysch lithologies) could be "injected into" or "overtake" more western material (young flysch). Late stage imbrication, on the other hand, also could bring up younger flysch from below the earlier detachment and juxtapose it with non-flysch lithologies in the melange-dominated eastern part of the field area (fig. 82). This imbrication requires a later detachment which developed under the original one in some areas. Thrusts associated with this late imbrication would correspond to the Taconic Frontal Thrust system observed elsewhere (Bosworth et al. 1988). This model provides therefore a more straightforward and elegant explanation for occurrences of younger flysch compared to the more complex normal fault model. The former model predicts normal fault contacts between overlying younger flysch above older non-flysch lithologies or flysch, which might perhaps be observed in structurally equivalent areas along strike with good exposure and observable shear sense indicators. In summary, the occurrence of a specific assemblage of non-flysch lithologies in some melange zones forces one to reconsider the whole accretion process of the Taconic allochthon. By weighing possible emplacement mechanisms against each other, it is concluded that both the non-flysch lithologies and at least parts of the accompanying flysch were assembled in front of the detached Taconic Allochthon probably as continuous slices early in the accretion history. Both non-flysch lithologies and some flysch are therefore considered to be highly allochthonous in nature.

Finally, the last in this list of general results of the field work is that west of the belts with major melange zones, there is a belt of deformed flysch with only incipient melanges and without non-flysch lithologies, west of which there is undeformed flysch. As mentioned, the strong contrast between the western and eastern parts of the field area argues against Vollmer's suggestion of a preserved "frozen" temporal succession of deformation now visible in a continuous and gradual west to east increase in deformation. The deformation itself in the deformed flysch suggests thrusting up to the western limit

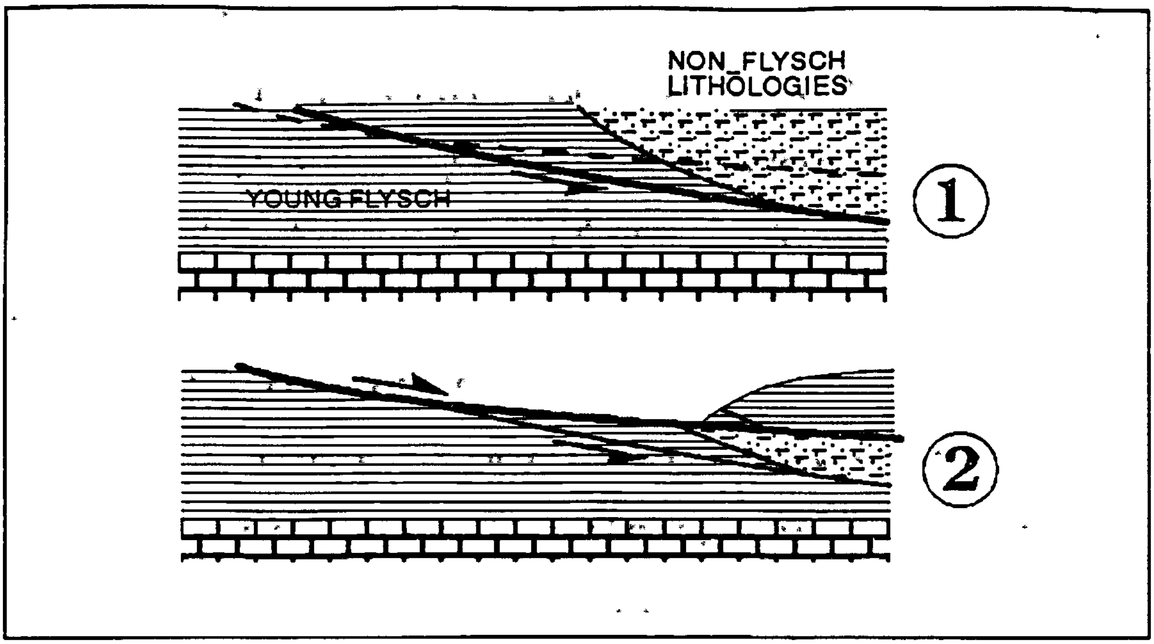


Figure 81 Low-angle normal faulting may place younger flysch above far-travelled non-flysch lithologies. Black lines are active faults, grey lines are inactive faults.

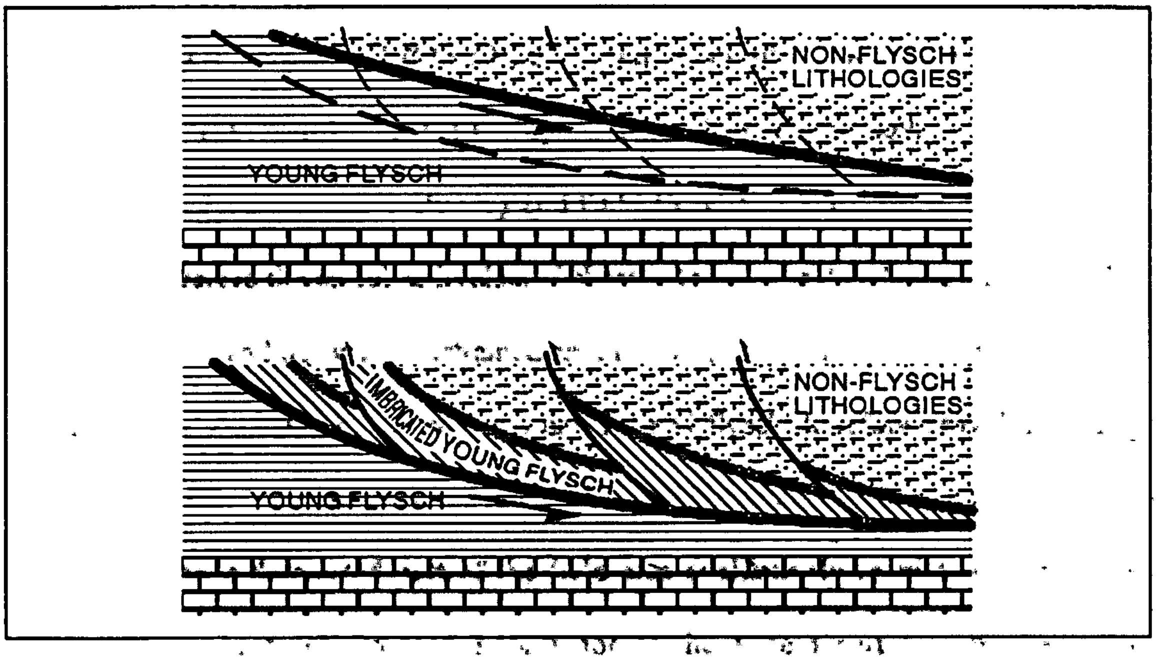


Figure 82 Imbricate thrusts join a sole thrust under an earlier detachment and bring up young flysch above non-flysch lithologies. Active thrusts are black, inactive thrusts are grey.

of deformation, the deformation front. It is difficult to constrain the amount of transport in this unit due to the lateral uniformity of the flysch sediments. By comparison with the surrounding units, however, it is possible to somewhat characterize the transport. There is a general lithologic contrast between the thin greywackes and siltstones of the Deformed Flysch and the thick bedded greywackes of Schenectady Formation in the undeformed flysch to the west. This contrast indicates that transport was sufficient to juxtapose different lithologic units. The amount of transport then depends on the missing stratigraphic thickness between these units and the dip of the thrust. If one assumes that the black shale under the Schenectady exposed along the Mohawk belongs to the same stratigraphic column as the thin greywackes of the deformed flysch and that the thin greywackes are close to the base of this shale unit and that typical thicknesses of black shale under the Schenectady are at least about 150m in this area (minimum of 457 ft. at drill hole DH-10, Stevens Elementary School, Ballston Lake, NYSERDA 1983) and that average dip of this thrust is 10° to 30°, then a minimum of the horizontal component of the displacement is calculated as ranging from 850.7m to 259.8m. The general diachroneity of sedimentation (Rowley and Kidd 1981) allows for a greater stratigraphic distance. Therefore the calculated value, if chosen to be considered at all in view of the obviously many and not well constrained assumptions, is a minimum value. The western contact of the deformed flysch with the undeformed flysch therefore provides a way to estimate minimum displacement amounts. The eastern boundary of the deformed flysch with the melange-dominated part of the field area qualitatively restricts the amount of displacement. The much stronger deformation in the eastern part as compared to the western part suggests that most of the time of ongoing emplacement, thrusts in the eastern part accommodated shortening and only towards the end of shortening the flysch in the western part of the field area became involved in this process. At this time it is not possible to further quantify the partitioning of shortening between western and eastern part of the field area. The step-character of the boundary between the two parts of the field area suggests that such a zone of deformed flysch was not formed for most of the time of emplacement and that the moving detachment did not incorporate a large amount of flysch into the overlying thrust stack. Instead, it followed its established position while growing into the foreland overriding essentially the seafloor. The slice of non-flysch lithologies and flysch, therefore, remained close to the main detachment thrust and, in fact, became part of it. The deformed flysch in the western part of the field area is, following this model, a result of the peculiarities of the final phase of shortening. In summary, the deformed flysch in the field area forms a sort of proto-thrust zone in front of the melange dominated eastern part of the field area which accommodated shortening possibly in the km-range at the end of shortening.

Summary

Integration of the major general results of my field work into the tectonic framework provided by Rowley and Kidd (1981) and Bosworth et al. (1988) leads to the following conclusions and addresses the question of how to interpret the obviously highly deformed rocks in the field area with respect to the position of a detachment. The structural features of the field area are explained from west to east. The deformed flysch unit is interpreted as a proto-thrust zone with unknown, but probably small cumulative displacement. A thrust separates it from the flatlying undeformed flysch and from the eastern melange-dominated two-thirds of the field area. It is thought that it accommodated substantially less shortening than the melange terrane to the east and may have been formed by the peculiarities of the final phase of collisional shortening. The Western Exotic Melange is the likely outcrop of the main detachment thrust under the Allochthon, which added a formerly continuous non-flysch-lithologies-plus-flysch-slice to the moving thrust stack and transported it far to the west over shelf carbonates and autochthonous flysch thereby forming extensive melanges in it and possibly including some younger flysch by low-angle normal faulting into it. Imbrication brought up younger flysch and melange zones and also produced melange zones by narrowly-spaced, steeply east-dipping thrusts. Steepening by back-rotation, repetition of exotic melange in belts and alternating melange-bedded flysch arrangements resulted. In the sketched tectonic history an initial emplacement thrust, which transported slope/rise lithologies onto the shelf, and a later Taconic Frontal Thrust System, which imbricated the emplaced allochthonous rocks and transported them further are only distinguishable insofar as younger interleaved flysch can be identified.

Melange Formation

Melanges form a significant part of the field area, in both volumetric and structural respect. In this chapter the processes and conditions responsible for the formation of these complicated rocks are discussed. A first part of this chapter identifies important properties of these rocks, a second part deals with the implications of those properties for the genesis of these melanges and a third part proposes a formation process in terms of the tectonic history. The term melange is only loosely defined (Hsü 1974, Raymond 1984, Cowan 1985, Rast and Horton 1989) and is applied to a variety of rocks. It refers typically to a chaotic rock with a block-in-matrix structure and irregularly cleaved matrix and often implies a not well understood formation process. The difficulties in definition are probably a consequence of the very diverse nature of the rocks compared. Therefore it is important not to rely too much on general theories on melange formation, but to recognize genetically significant properties of the specific melange in the field area.

Vollmer (1981) and Vollmer and Bosworth (1984) studied melange in outcrops close to the field area and proposed a formation process which involved both tectonic disruption via structural slicing and soft-sediment olistostromic disruption. Vollmer (1981) found good evidence for hard rock disruption (see heading Vollmer's map). Down dip striations on shale phacoids and observable offsets across the phacoidal cleavage demonstrate a micro shear nature for the cleavage. The occurrence of an olistostromic deposit and pebbly mudstones and complex, polyphase deformation of the Normanskill melange, which may indicate slumping processes prior to tectonic deformation, suggested to Vollmer and Bosworth (1984) that soft-sediment deformation was an integral part of melange formation. I found that preserved and observable olistostromes and pebbly mudstones are exceedingly rare. The outcrop south of Rensselaer at the east side of Rt. 9J, which is referred to by Vollmer (1981), remained the only one found during my field work displaying characteristics of an olistostromic chaos. Pebbly mudstone is also rare and thin and associated with non-flysch lithologies. The complex, polyphase deformation of the Normanskill melange may equally well be the result of a prolonged tectonic emplacement history. A comparatively long and complex strain history is indeed suggested by the tectonic model proposed above (fig. 80), if the greywacke of the Normanskill melange is related to the nearby Glenmont chert slice (Vollmer 1981) and is therefore far travelled. For these reasons I do not think that sedimentary processes played a major role in the melange formation process. Consequently the following is directed toward a more full description of the tectonic environment and processes responsible for melange formation.

Properties of Melanges in the field area

Melange was studied in detail along the Mohawk River at Cohoes Gorge and along Rt.7, Latham by me. Bosworth (Vollmer and Bosworth 1989) studied incipient melange at Vischer Ferry in the field area and melange along the Hoosic River at lower Schaghticoke Gorge and other localities in the Hudson Valley. Vollmer (1981) made a detailed structural map of the Normanskill melange. Xia (1983) examined the cleavage in melangy shale in detail from near the Taconic Frontal Thrust in Troy. This extensive body of work on essentially the same melange allows one to recognize and exactly describe some properties of this melange. The material which forms the melange and the fabric or geometric arrangement of structural elements of the melange are two categories to be described. The fabric is the defining element of the melange and is described in more detail.

Material

Flysch sediments - shale, siltstone and fine-grained greywackes - are the main constituents of the melange, in this order. Shale and siltstone are always present. In certain zones of the melange a characteristic assemblage of non-flysch sediments occurs (fig. 63). A coarser greywacke may be associated with the non-flysch lithologies. There are also greywacke-rich zones. The significance of the occurrence of a specific assemblage of non-flysch lithologies has been discussed above.

Fabric

The following structural elements are distinguished in the melange: foliations due to bedding, cleavage and veins; lineations due to striations on cleavage and slickenlines on veins; and the overall fabric due to the morphology of the blocks and a block-in-matrix structure. They can be observed on an outcrop scale and on a microscopic scale. The extraordinary thickness of melange zones is discussed.

Bedding

Preserved bedding is rare as observed at outcrop scale. It can be observed only in intact blocks and slices of shale, siltstone, greywacke and non-flysch lithologies. Coherent bedding in an extended volume is, in the end, the defining property of a block distinguishing it from the pervasively cleaved matrix. Alignment of three and more carbonate breccia blocks in horizons which dip more gently east than the main melange foliation as observed at Cohoes Gorge can be interpreted as relict bedding on a larger scale. In some greywacke-block-rich melanges, blocks can be identified as formerly belonging together. In the Normanskill melange, for example, dismembered, steeply plunging folds can be inferred from bedding in greywacke blocks (Vollmer and Bosworth 1984). Similarly, below the Cohoes dam bedding in larger bedded slices can be correlated across thin zones of disruption to infer larger scale folding. On the other hand, in the greywacke rich melange of Anthony Kill, tracing of bedding is strictly restricted to single blocks. Contacts of melange with larger bedded slices are transitional and are not bedding planes. In thin-section the distinction between bedded blocks in cleaved matrix cannot be used anymore because it is too large scale. Bedding in thin-sections of cleaved matrix shale is commonly recognized (Xia 1983, Vollmer and Bosworth 1984, Bosworth 1989) as variations in grain size and quartz grain content. Bedded domains are separated from each other by discrete cleavage planes in a variety of orientations. Judging from published descriptions the orientation of bedding in thin-section seems to be subparallel to the orientation of the main melange foliation, but the relation between bedding and cleavage was not the main focus of these investigations.

Bedding is only a minor fabric defining foliation. Although bedding can often be recognized in the low-grade rocks forming the melange, in blocks in the outcrop or in the matrix in thin-section, it is usually impossible to trace a bedding plane for any significant distance. A significant distance is defined by comparing the extent of bedding with the extent of disruption. Accordingly it is meant to be a small multiple of the average spacing of the disrupting anastomosing cleavage (mm to cm) or average block spacing (meter) depending on the rheology of the bedded material.

Cleavage

The anastomosing cleavage in the melange matrix is the most distinct fabric element. It is also referred to as phacoidal cleavage (from greek ***phakos*** = lens, and *eidos* = shape), emphasizing the shape of the volume (the phacoid) enclosed by the cleavage. Scaly cleavage is another term sometimes used. However, its usage may imply some systematic overlapping of shale chips in an imbricate sense which is not observed. In this text the adverb "phacoidally" was preferred over the awkward "anastomosingly".

The cleavage lamellae in shale and siltstone are typically spaced some mm to some cm apart. Xia (1983) gives average values from 1mm to 5mm measured with the naked eye normal the general cleavage plane. The cleavage lamellae produce phacoids which often look crudely rhombohedral, particularly when observed in sections parallel to strike. The phacoid surfaces often look polished - especially when freshly exposed - and sometimes show soapy rainbow colours due to thin film interference effects. The surfaces often exhibit fine striations. The phacoids are aligned inasmuch as their shape usually defines a similar main plane, which divides more or less equally the angles formed between the cleavage lamellae. Together with slab-shaped blocks parallel to this plane, these foliations define an average melange foliation. It is interesting, however, to note that where good exposure allows one to observe extensive melange on a scale of 50m to 100m, the across strike view of this melange foliation differs much from the along strike view. In vertical sections across strike the trace is well defined and straight, whereas in vertical sections along strike the trace is very wavy. On this larger scale therefore a strong moderately to steeply east-dipping lineation seems to dominate at least in places over the average planar features of the melange.

Xia (1983), Vollmer and Bosworth (1984) and Bosworth (1989) measured orientations of the cleavage lamellae. It is difficult to measure the orientations in three dimensions, because of the smallness of the phacoids and their irregularity. Therefore the trace of the cleavage lamellae is observed in sections. Whereas Vollmer and Bosworth (1984) observed two strong maxima centered around the main melange foliation in sections cut perpendicular to the main melange fabric and both in down dip and along strike directions, Bosworth (1989) noted in a down dip section a strong maximum parallel to the main melange foliation. The acute dihedral angle between lamellae or the maximum angle between two cleavage lamellae is 30° to 70°. In Xia's (1983) samples the lamellae do not show maxima, but are more evenly distributed around the main melange foliation. In the cut parallel to the strike they diverge much more (dihedral angle of ca. 80°) than in the cuts in dip direction (dihedral angle of ca. 50°).

Xia (1983) investigated also in three dimensions the geometry of the anastomosing cleavage by serial sectioning. He found that many cleavage surfaces do not extend for long distances (some cm) in any direction. By measuring strikes and dips of cleavage lamellae correlated across serial sections, he arrived at two stereographs (fig. 83) showing contours of presumably poles (not explicitly mentioned) of cleavages, one for serial sectioning in the dip direction (191 measurements) and one for serial sectioning along strike (127 measurements). Contours in the dip direction stereograph show only two well defined maxima. The angle between the corresponding planes (ca. 40°) is bisected by the main melange foliation. The intersection of the corresponding planes is the dip direction of the main melange foliation. Contours in the strike direction stereograph do not show a strong maxima but define a great circle approximately perpendicular to the main melange foliation and to the dip direction of the main melange foliation. The corresponding planes can include any angles with each other and intersect each other in the dip direction. A weak maximum shows that many planes include only a small angle with the main melange foliation and dip more steeply than it. Although both attempts of measuring cleavage orientations should result in the same set of orientations, it is clear that due to restrictions of measuring, differences can be expected. Cleavage lamellae roughly parallel or almost exactly perpendicular to the sectioning plane, for example, cannot be measured and will be under-represented in the stereographs. Therefore the two stereographs should not be compared with each other, but should be seen as a partitioned description of one phenomenon. The results are consistent with Xia's two dimensional trace results. Additionally they show that the down dip direction is the preferred intersection direction of the cleavages. Fig. 84 shows the constructed shape of one half of a typical phacoid, if densities in the stereograph are interpreted as relative sizes of areas of the phacoid sides. Fairly flat shapes, elongate in the dip direction, result. Whereas

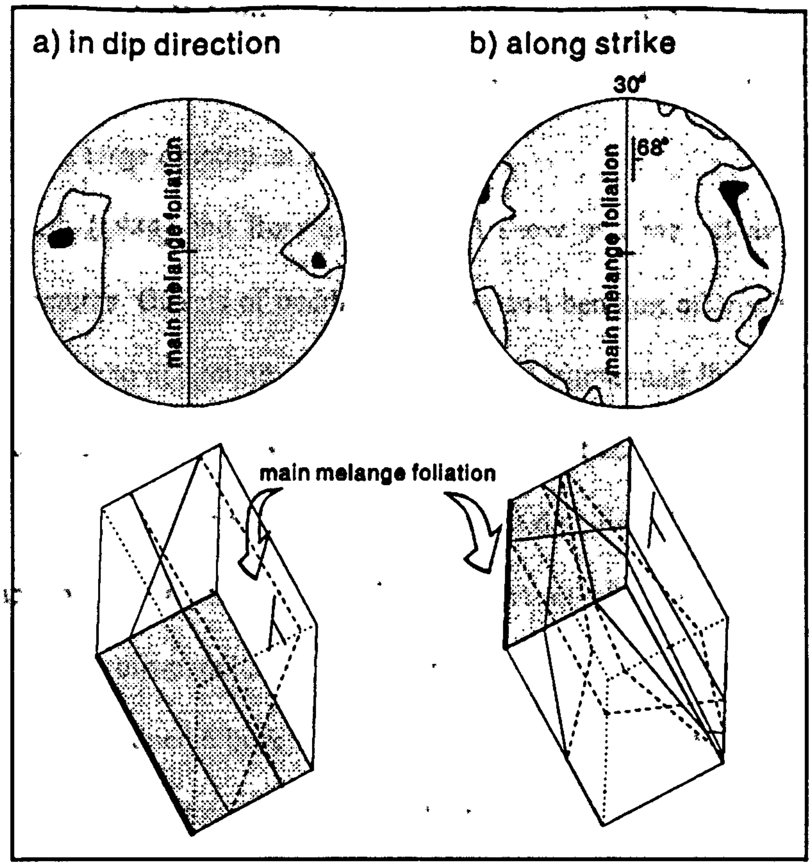


Figure 83 Stereographs show cleavage orientation measured by Xia (1983) in serial sections in dip direction and along strike. Contours are envelopes (>0%) and maxima (>10%). Planes of circles are sectioning planes. Boxes are for visualization. Note that different methods measure different orientations (modified from Xia 1983).

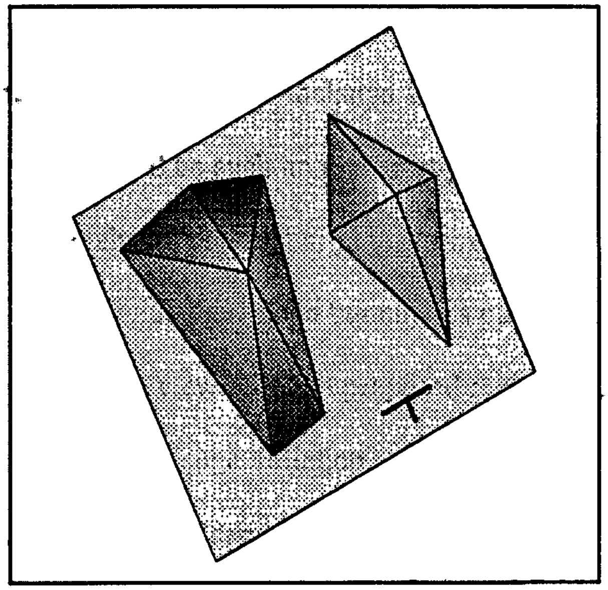


Figure 84 Two examples of typical phacoid shapes consistent with contours of stereo-graphs (fig. 90). Contours require fairly elongate and flat shape.

these characteristics of phacoids are not immediately obvious in the field, it is interesting that the lineation defined by the elongate shape is parallel to the large scale lineation in the dip direction observed in a large outcrop as explained above.

Vollmer and Bosworth (1984) and Bosworth (1989) show that the cleavage lamellae are micro shear fractures. Offsets of bedding markers and bending of fissility towards a micro shear enable one to determine the sense of shear. Vollmer and Bosworth (1984) and Bosworth (1989) identify the sets of cleavage lamellae traces observed in sections as extensional conjugate slip systems with principal strain directions in the plane of the main melange foliation and perpendicular to it. The amount of disruption and offsets observed suggests that dip-parallel extension often exceeds strike-parallel extension. From this the authors deduce a bulk strain state $S_1>>S_2>1>S_3$ with $S_{1/2}$ in the main melange foliation (where S, the stretch, is deformed length / undeformed length). As a reasonable S_1-direction, Bosworth (1989) chooses the dip direction, which may not necessarily be concluded from the trace data, but is the most straightforward choice. This bulk strain state may be a result from pure shearing or simple shearing or both. Systematic asymmetries which would indicate non coaxial flow are difficult to observe in the complex fabric. The weak maximum towards steeper melange lamellae in the along-strike stereograph of Xia (1983) (fig. 83) would be such an asymmetry, if it could be confirmed in other samples. In the discussion above, regional arguments were used to advocate a view of melange zones as shear zones with shear zone boundaries parallel to the main melange foliation. In order to reconcile this view with the proposed strain state and with extension in all directions in the main melange foliation, an uncertain but probably high simple shear must be added to some necessary component of pure shear.

Another (?) component of simple shear is recorded by throughgoing micro thrusts parallel to the main melange fabric observed in sections in the dip direction (Bosworth 1989). Xia (1983), in mapping a thin section of anastomosing cleavage, describes similar thrusts as an early fabric cross-cut by a later conjugate set of cleavages.

A mesoscale observation strongly suggests a simple shear origin for the anastomosing cleavage. In an outcrop where bedded coherent greywacke slices become fairly large (below the Waterford Dam, 266) a bedding parallel thrust was observed, which crosses a greywacke bed and turns into a widening zone of phacoidally cleaved shale cutting across bedding.

This observation is also important for understanding the process of formation of anastomosing cleavage. Anastomosing cleavage may be an end result of progressive shear or it may be an alternative, steady-state mode for shear zones. The occurrence of small localized melange shear zones with an apparently limited history favours the latter steady-state option. Xia (1983) repeats a suggestion of Vollmer and Bosworth (1981) according to which cleavage surfaces were initially formed perpendicular to the maximum principal stress and then rotated and activated as shear planes under progressive shearing with simultaneous initiation of new cleavage surfaces perpendicular to the maximum principal stress. This process-oriented model can explain crosscutting relations which indicate simultaneous activity. Alternatively Bosworth (1989) points out that high strain rates also lead to complex crosscutting relations. This is more compatible with the steady-state model, which is preferred.

Another constraint on the formation of anastomosing cleavage is mentioned by Bosworth (1989). The extent of dewatering of the precursor material does not seem to play a role for formation of this cleavage, because development of such cleavage was observed in both only partially consolidated core samples from recent accretionary prisms and in transitions from uncleaved and slaty cleaved shale, which was completely dewatered, to melange.

Detailed study of the anastomosing cleavage (Vollmer and Bosworth 1984, Bosworth 1989, Xia 1983) shows that the cleavage lamellae are micro shears that brittlely deformed the matrix shales and siltstones. Statistical analysis of cleavage lamellae in three dimensions in one sample and large scale outcrop observations indicate a pervasive lineation moderately to steeply east-dipping in the melange. Shear sense analysis of conjugate traces of slip systems observed along strike and down dip show extension in the plane of the main melange foliation. Because shear zone boundaries are probably more or less parallel to the main melange foliation, this requires a probably high simple shear component and some pure shear component. It is suggested that the formation of anastomosing cleavage is the steady state result of shear zones in a mode which corresponds to high strain rates and does not require a long history.

Veins

Quartz-calcite veins are in places frequent in the melange. Several types of veins can be distinguished. There are irregular vein arrays often with large "pegmatitic" crystals and cavities, folded veins extending only for short (<0.5m) distances and some striated, essentially planar veins which are almost always multilayered and slickensided and which sometimes have cavities, and micro vein arrays and limonite fillings (Xia 1983).

Discontinuous folded veins and vein arrays demonstrate earlier deformation and melange formation in a sufficiently lithified and dewatered rock. Essentially planar, slickensided veins are always extensive and provide a comforting contrast in their orderliness to the chaotic melange. They seem, however, to be related to melange formation, because they occur most often in good melanges, but rarely or never in the large bedded slices or the deformed flysch to the west. They produce a sense of a cross-cutting relation to the phacoidal cleavage, because they are planar and extensive in contrast to the phacoidal cleavage and have a different dip than the main melange foliation. Actual cutting, though, was only observed once; at the top of the largest carbonate breccia slab observed at Cohoes Gorge, at the top of the path down to the river, where above the cm-thick slickensided vein the carbonate breccia is missing. These two observations - slickensided veins are related to melange formation, but probably postdate it - suggest that slickensided veins formed at the final stage of melange formation and that, therefore, melange formation was a multistage process. That the slickensided veins itself are a composite product of an ongoing process is demonstrated by the often slightly different orientation of slickenlines on dark surfaces of sublayers of multilayered veins. Towards the end of melange formation, the deformational environment seems to have been such that displacement was not any more accomplished in a distributed manner by broad melanges but in a more common mode by well defined and often reused slip surfaces. Also, the melange must have had a sufficient strength in order to yield to stress by extensive planar veining ignoring the apparently weak cleavage surfaces in the melange. The amount of slip on these slickensided veins is thought to be minor inasmuch as in only one case are lithologically or structurally differing units juxtaposed across the veins. The exception is an exposure of the Taconic Frontal Thrust by the Poestenkill (211, see map in map pocket). Here an extremely block-rich melange underlies folded Taconic lithologies. The contact is sharp and everywhere defined by slickensided veins. Although here slickensided veins do juxtapose important units, which may indicate more significant slip, it is more likely that the more gently dipping veins modified a former steeply dipping transitional contact as it is observed at two other exposures of this thrust (357 and at Mt. Merino east of Catskill). Then slip must be only in the order of the transitional width to juxtapose sharply melange and Taconic lithologies assuming a vertical transitional contact and an 50° east dip for the slickensided vein.

Striations

Lineations in the melange are found mostly in form of striations on surfaces. Other lineations include a possible elongate shape of phacoids (derived from one sample), a large scale lineation defined by waviness of the main melange foliation (in broad sense similar to fold hinges), and fold hinges of the numerous rootless folds (see block morphology). Two kinds of striations are observed. 1) The anastomosing micro shear planes of the melange as exposed on surfaces on phacoids are often very finely striated. 2) The dark and thin layers of multilayered planar quartz-calcite veins are almost always striated. The orientation of phacoid striation is difficult to measure and seems to vary considerably. Xia (1983) mentions rare "radiative patterns of striations", probably referring to striations radiating away from an apex of a phacoid as the origin. Vollmer (1981) refers to those striations as down-dip striations, indicating east trends for the striations. Vollmer and Bosworth (1984) mention that striations most often occur on east dipping surfaces, but also on other surfaces (more north or south dipping). Scanning electron micrographs of cleavage lamellae (Vollmer and Bosworth 1984) surfaces show abundant striations with spacings between ca. 10µm and 50µm.

Orientation of slickenlines on veins were measured and often trend approximately 110°.

The nature of striations similar to those on vein slickensides is described in Means (1987). His striations are from dark shales from the Rt.7 outcrop and from a deformed wax sample. Means (1987) concludes that the observed nesting of similarly shaped flat U-shaped mm-spaced ridges and grooves on both sides of a split dark slickensided layer is not compatible with any conventional mode of formation of slickenlines, asperity related or mineral growth related. Characteristic of all five conventional types of slip-parallel linear features on slickensides he mentions is that the striation is actively created only at one moving irregularity (step in the slip plane or asperity) in the slip plane. For the type recognized by Means (1987) no creating irregularities can be employed, because the edges are very long in the slip direction relative to their spacing and they are as many grooves as ridges on either side of a split slip plane. The question is here what leads to the edges of the up and down stairs or U-s in the profile of the shear surface which define the striations. What process favours this shape over just a planar surface? From the properties of this lineation it is clear that this shape is a result of the process only and not of inhomogeneities in the material, because the striations were found in different materials which are both very homogeneous. It is also clear if there is an edge that it will extend over a considerable distance in the slip direction to avoid space problems. Therefore the edges probably develop very early in the slip process and are then stable. Will and Wilson (1987) were able to reproduce this kind of lineation experimentally. From their observations they conclude that this lineation develops in an early ductile initiation phase of a shear zone. Later brittle accommodation of strain along the fault plane can preserve this lineation (Will and Wilson 1987). The authors suggest that ridges and grooves develop by propagation (faster than strain rate) of C-planes (parallel to the shear zone boundaries and the later fault plane) which follow in detail (0001) planes of layer silicates. Unlike in the striated shale sample (Means 1987) grooves and ridges in the dark layers of slickensided veins seem to be defined by the surface of the underlying calcite, which seems to be just coated by the dark material.

Fine striations on phacoids show the shear origin of the cleavage lamellae. Quantitative, statistical analysis of their orientation is difficult, but limited qualitative observations are consistent with the state of strain proposed from analyses of the anastomosing cleavage. Striations on slickensided veins trend at an high angle to the regional strike, but are not exactly perpendicular to it. Experimental work (Will and Wilson 1987) showed that similar striations initiate in ductile shear zones which may later become brittle faults.

Block morphology

Blocks in the melange are bounded by discrete, sharp boundaries and are internally coherent. In general, blocks are not very frequent in the melange. Phacoidally cleaved shale and siltstone dominates. Block-rich zones can be distinguished from block-poor or block-absent zones. Besides the internal coherence of blocks their lithology also defines them as distinct from the surrounding shale/siltstone matrix. There are some shale blocks, but most blocks are greywacke blocks. Shapes can be subdivided in slabs, blocks *s.s.* and tight fold hooks. Slabs are planar and are the most frequent morphology observed, blocks *s.s.* have no preferred dimension in their shape and fold hooks are sliced off fold hinges which range considerably in size (from limb to limb from some cm to 2m). The main plane of the slabs is often sub-parallel to the main melange foliation and, in fact, helps define it. Sometimes normal faults which cut the slab and are restricted to it can be seen which result in extension in the dip direction. Sliced off fold hinges are fairly frequent. Their axial plane is subparallel to the main melange foliation. The plunge of the hinge lines varies. Hinge lines are rarely horizontal and often plunge steeply. Assuming initially horizontal hinge lines the reorientation of those to steeply plunging orientations has been utilized (Vollmer and Bosworth 1984) to infer a minimum shear strain γ of 10.

Block morphologies are consistent with a strain state which involves extension in the plane of the main melange foliation and shortening perpendicular to it.

Block-in-matrix zones

Block-in-matrix structure is observed regularly in the melange. Whereas many smaller outcrops do not expose such a structure, but only phacoidally cleaved shale and siltstone, all larger continuous outcrops in the melange have parts with good examples of mesoscale block-in-matrix structures. Despite the smaller-scale chaotic appearance of the melange, observable zones of block-rich, block-lacking, or non-flysch-lithologies block-bearing melanges indicate a certain preserved order on the 100m scale. Mixing of an originally well ordered sediment column by melange forming processes was incomplete on this scale. It is believed that both the greywacke blocks in a block-rich melange and the blocks of non-flysch-lithologies are derived from certain restricted sections in the original sediment column. The contacts between those block-rich melange zones are tectonic. On a smaller scale, disruption and boudinage is very thorough: Whereas block morphology often indicates a tectonic origin for the blocks, a small number of places show a readily identified sedimentary nature of a different block-in-matrix structure. The olistostrome seen east of Rt.9J south of Rensselaer features an uncleaved matrix and irregularly shaped very poorly sorted blocks of any size (mm to 1.5m) which float in the matrix. Rare pebbly mudstone found in melange sections which carry non-flysch-lithologies is similar to the finer grained portions of this olistostrome. One very coarse conglomerate with extremely well rounded, spherical carbonate breccia clasts floating in a dark-brown silty matrix was also found (Cohoes Gorge section, fig. 45).

Whereas block-in-matrix structures on a small scale (<10m) indicate thorough mixing on this scale, larger scale (>100m) zonations indicate some preserved coherence and incomplete mixing. Readily identified sedimentary block-in-matrix structures are observed, but are very rare.

Thickness of melange zones

Melange zones in the melange-dominated eastern part of the field area can have structural thicknesses in the km-range. The continuous exposure at Cohoes Gorge of good melange, uninterrupted by coherent slices thicker than 10m, extends for 3km across strike. At an average dip angle of 45° this gives a structural thickness of 2.1km. Such large thicknesses of fault zones suggest strain hardening under progressive deformation. When the strength of the fault rock exceeds the strength of the wall rock the fault will be locked and the wall rock begins to become part of the fault zone. The fault progressively becomes thicker. Therefore the intensely cleaved melange should be stronger than shale and siltstone, likely wallrock material. It is surprising that the introduction of a large number of weaknesses (cleavage lamellae) can strengthen a rock. It seems that the more isotropic distribution of weaknesses is what gives the melange a strength advantage over coherent shale and siltstone with well ordered weaknesses (bedding). This is suggested on a small scale (<1m) by the observation of the widening of a discrete bedding parallel thrust into a zone of phacoidally cleaved shale. It is of interest to investigate under which conditions (e.g. normal stress, fluid pressure, orientation of anisotropies) the strength advantage of the melange holds, but is beyond the scope of this thesis.

Interpretative summary of melange properties

The diverse properties of the melange are briefly discussed above and are summarized here.

Bedding is usually traceable only for short distances in the outcrop scale. This implies frequent and narrowly spaced faulting. This faulting is accomplished by the anastomosing cleavage, which probably developed early in the history of the shear zones in a way which is independent from the water content of the host material. The cleavage surfaces are micro shears, which accommodated extension in the plane of main melange formation and shortening perpendicular to it. A probably high amount of noncoaxial flow coupled with some coaxial flow is responsible for this strain. The shear sense of the simple shear component is unclear from observations on the melange, probably because of rotation of material lines into parallelism with the shear zone boundaries. Regional geology, however, strongly suggests an east over west thrust sense (Rowley and Kidd 1981). Fairly frequent deformed and undeformed, crosscutting, veins show that melange formation was a multistage process. Towards the end of melange formation deformational parameters (strain rate, P/T-conditions, fluid pressure) were such that slip on narrow, well defined veins dominated over distributed displacement by anastomosing cleavage. The steep plunge of fold hinges, which occur as blocks in the melange, has been used to infer a shear strain γ in excess of 10. Mixing on a scale less than 100m was so thorough that no original relationships are recognizable. On a larger scale zonations become observable, which indicates incomplete mixing on this larger scale. The great thickness of the melange zones is thought to be a result of strain hardening and successive outward migration of shear-zone boundaries.

The complex nature of these rocks results in diverging constraints on their formation. On the one hand phacoidal cleavage seems to develop early, on the other hand melange formation was a multistage process. On the one hand melanges accumulated high strains, on the other hand at a certain point they locked and forced widening of the shear zone. On the one hand water content is not important for phacoidal cleavage development, on the other hand late veining is related to melange formation. Mixing occurred, but is scale dependent.

Melange Formation as suggested by a structural synthesis of the study area

Results of the previous chapter "structure and local implications" concerning melange formation are summarized here. These results are based on general results of my mapping and the tectonic setting in which these melanges occur. The structural synthesis suggested that the extensive melanges of the eastern part of the field area represent the imbricated main detachment thrust which emplaced the Taconic Allochthon onto shelf carbonates. It also suggested that the detachment did not build into the foreland for most of the duration of emplacement. Instead, the detachment continued to utilize the established thrust surface keeping the frontally accreted non-flysch-lithologies-and-flysch slice at the deformation front and essentially overriding the seafloor and freshly deposited flysch. This flysch and the whole frontal slice became tectonized to form melange. Therefore the site of melange formation is the plane of main detachment. The melange and younger flysch was brought up and tectonized by late imbricate thrusts which joined into a later detachment located under the main detachment in this area. Following Vollmer and Bosworth (1984) and having in mind the melange zones as the main detachment, previous estimates of the total displacement along the main detachment can now be used to infer bulk shear strains in the melange. Rowley (1983) calculated a minimum of 80km for this displacement using paleogeographic arguments. For a 11km wide shear zone, the total width of the eastern melange dominated part of the field area, with boundaries parallel to the main melange foliation dipping 45° to 60°, this displacement results in a bulk shear strain of 10.3 to 8.4. These are minimum values for local shear strains in the high-strain parts of melange zones. The choice of the dip range of this shear zone is important because the dip controls its thickness and the shear strain at a given displacement. Smaller dips would result in much higher shear strains. The predominance of the mentioned dip range in the melange foliations and melange/slice contacts and the absence of gentle dips (<20°) lead to the conclusion that the shear zone boundaries are also steeply dipping. This conclusion is based on field evidence and is somewhat inconsistent with conclusions of a more general nature, and those based on observations north of the field area. Major detachment thrusts are generally gently dipping to subhorizontal (Gosh 1993) in order to accommodate large scale horizontal shortening. In the field area and in the Taconic Allochthon the metamorphism is of low grade (characterized just by enhanced illite cristallinity) and thrusting was generally not basement-involved (Rowley and Kidd 1981). Therefore low depth values (< 5km ?) contrast with high horizontal distances (width of allochthonous mass ca. 30km and larger displacement) and the detachment thrust must be gently dipping to subhorizontal at depth. Direct evidence for a gently dipping detachment at the present day surface was found to the north. It is possible to trace the melanges of the field area to the north into the Champlain Thrust system (discussion see p. ???). Outcrops of gently east dipping thrusts including the main Champlain thrust (Stanley 1987) and map patterns suggesting gently dipping thrust contacts (Bosworth et al. 1988) clearly show that the main detachment there dips very gently east. Also, a COCORP profile (Brown et al. 1983) managed to image gently dipping reflectors which cut the land surface at a position approximately where geology puts the Champlain thrust.

The introduction of a significant dip change from north to south requires more detail and complexity in the description of the main detachment. Three possible explanation for the change from gentle dips in the north to steep dips in the south are change in the exposure level from deeper more eastern levels in the north to shallower more western levels in the south (fig. 85, top) or real change in the shape of the detachment surface in a lateral ramp fashion (fig. 85, bottom) or a combination of both. Doming of the Adirondacks suggests that adjacent areas to the east could have been subjected to more uplift than areas to the south of the Adirondacks and therefore supports the exposure level hypothesis. Although Adirondack doming may be the most obvious candidate for exposure level change, it is probably not the dominant contributor to exposure level change. Taconic and/or Acadian tectonism or perhaps even Jurassic rifting provide well known and potentially more effective mechanism for exposure level change. In contrast to the exposure level hypothesis, the lateral ramp hypothesis predicts significant changes in the overall structure of the transported mass above the dip-transitional area of the detachment (the lateral ramp). Specifically a change in the transport direction from 110°-120° to more SE-NW (135°, depending on the smoothness of lateral ramp) is expected which should be detectable in the attitude of melange foliations, fold axial planes or lineations between Saratoga Lake and north of Glens Falls at the latitude of the COCORP line. Limited mapping by Bosworth (Vollmer and Bosworth 1984) in the Schuylerville area identified melange belts parallel to the regional strike and no unusual attitudes of structures, thereby not supporting the lateral ramp hypothesis.

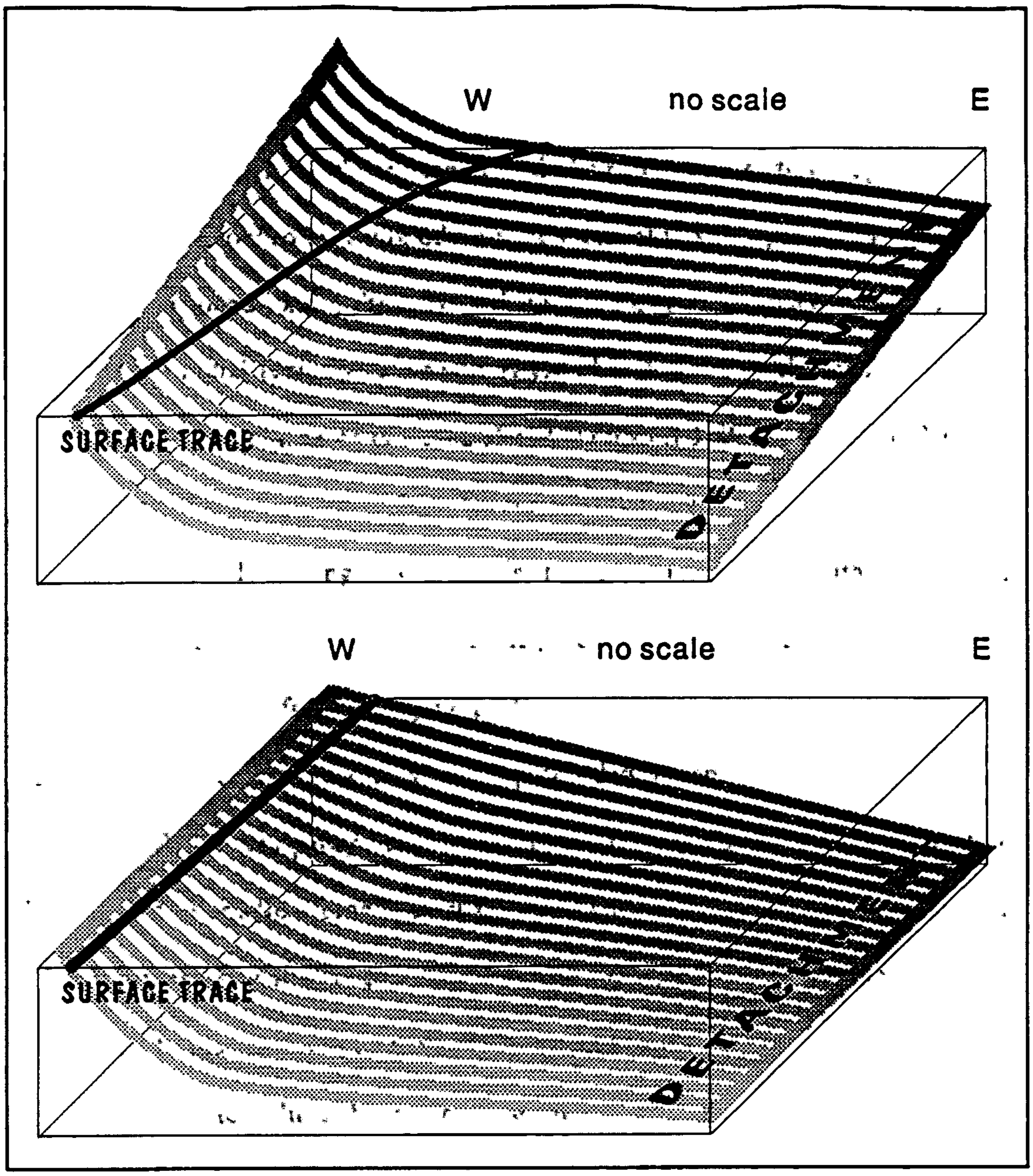


Figure 85 Two endmember hypotheses can explain a change in the observed dip of the surface trace of the main detachment. Top) A deeper erosion level in the north exposes a deeper and more eastern section. Bottom) The dip changes according to a lateral ramp like geometry of the detachment surface.

Integrated model of melange formation

The properties of the melange and their tectonic setting suggest formation dominated by prolonged exposure of melange material to shear processes. The following history is envisioned for the formation of the melange as a multistage process. The first stage was the initial accretion of the non-flysch-lithologies-and-flysch slice to the front of the moving thrust stack of detached slope/rise material. Probably phacoidal cleavage development, disruption and veining occurred already in this stage, but mixing was restricted. Chert-only melange (102, 402) is attributed to this stage. With increasing shear strain across the main detachment the shear zone widened. The compatibility of bulk shear strains derived from plunging fold hinges and paleogeographic considerations indicates that the widening may have proceeded at an overall fairly steady rate. Overridden flysch was partly incorporated in the melange by minor accretion, footwall plucking and return flow processes in the accreted mass. These processes played a role in local mixing as well as out-of-sequence risers from the main detachment which also contributed to the widening of melange zones and thickening of the frontal slice. They are responsible for slices bound by melange zones. Towards the final phases of emplacement and melange formation, active detachment took place locally under the established detachment and led to imbrication and inclusion of younger flysch slices. Through all this thrusting a stable phacoidal cleavage mode was preferred by shear zones accommodating faster strain rates. Finally this mode was substituted by (slower overall) displacement along discrete veined faults.

REGIONAL GEOLOGY, CONTINUITY AND VARIATION ALONG STRIKE

Introduction

My mapping has resulted in a new model for explaining the geology of the field area. Therefore my mapping suggests a critical reevaluation of available basic data for other areas in an equivalent setting in the central Hudson Valley (fig. 86). This was the initial reason to begin to compile the geology of a larger area. Reevaluation and integration along strike serves two purposes: testing the locally derived model and improving the understanding of regional geology. The test in mind is not a true/false test. One tests just if the locally derived model can be applied without major difficulties to other areas. If one succeeds, the result - a new map or tectonic model - is most likely an improvement because a large amount of data was used in a consistent manner.

The compilation shows that the inferred tectonic model including a proto-thrust zone, an imbricated main detachment and small slices is compatible with the geology of other areas to the south. This chapter describes the methods employed for the compilation, summarizes the available data, presents and discusses the results of the compilation and suggests a larger scale tectonic model.

Methods

The following steps were carried out in order to compile the geology in the Hudson Valley from Saratoga Lake to Newburgh, NY. First, relevant material containing basic geologic data was identified and accessed. Previously published maps and field trip guidebooks and unpublished maps of a SUNYA mapping course provided useful geologic data (fig. 87). Additional data were collected in the field when key exposures were visited. Then the data from those various sources were organized. A base map was prepared (see appendix) and the location of reported outcrops were indicated. Available structural information was added. Then, based on the available lithological and structural information, and experience gained during fieldwork, units were identified and their boundaries traced. Fig. 88 is a summary version of the resulting map (in map pocket).

Geology of the 15' - quadrangles

The information used for the compilation is described for each of the 14 15'-quadrangles proceeding from north to south.

Schenectady

Useful information is described in detail in this study for the eastern, deformed section. Ruedemann (1930) describes the Schenectady Formation in the western, undeformed section.

Cohoes

The mapping for this thesis is the main source of information, and is described

Figure 86 Ordovician Flysch in the central Hudson Valley (shaded) and names of 15'-quadrangles

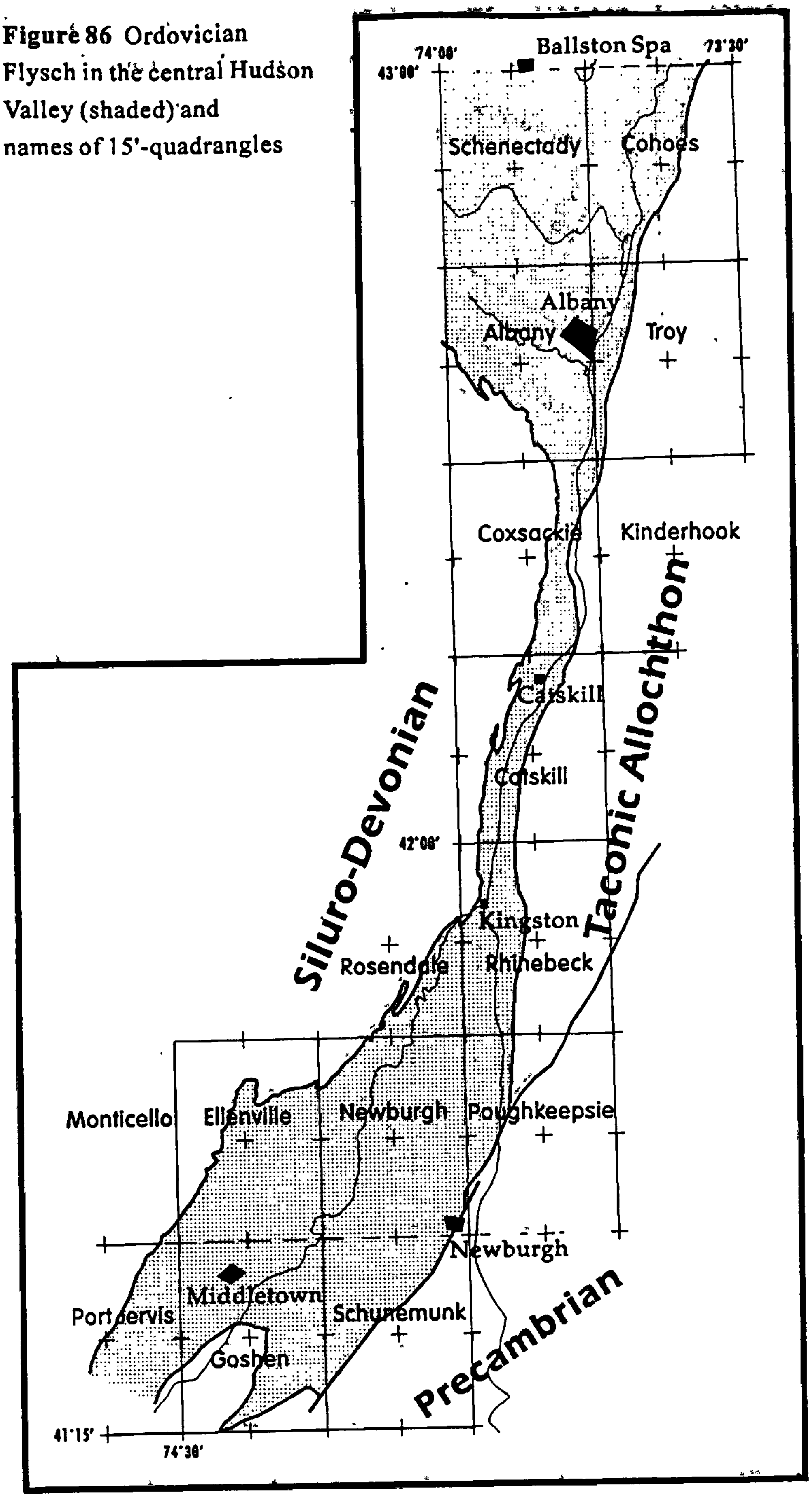
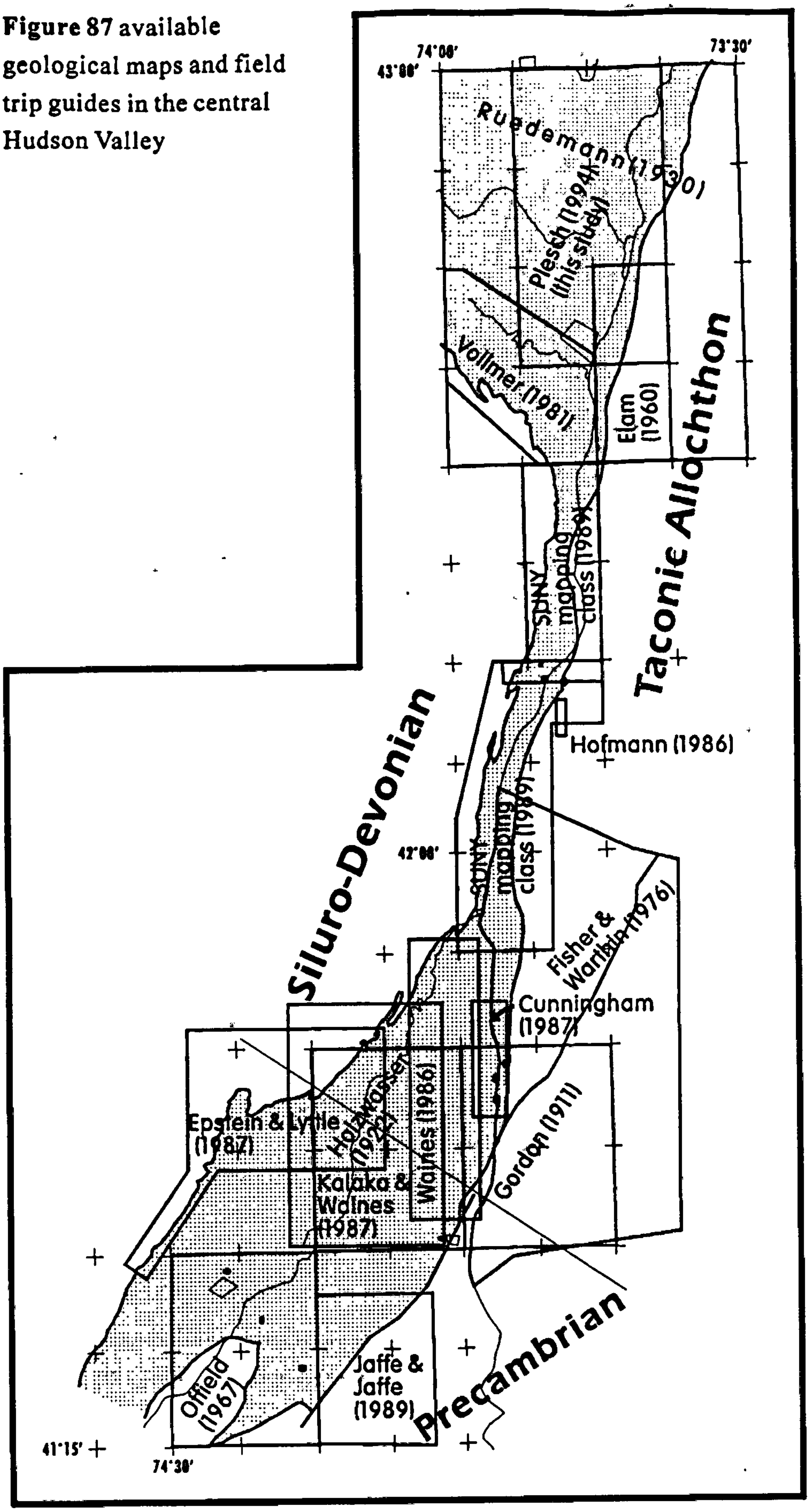


Figure 87 available geological maps and field trip guides in the central Hudson Valley



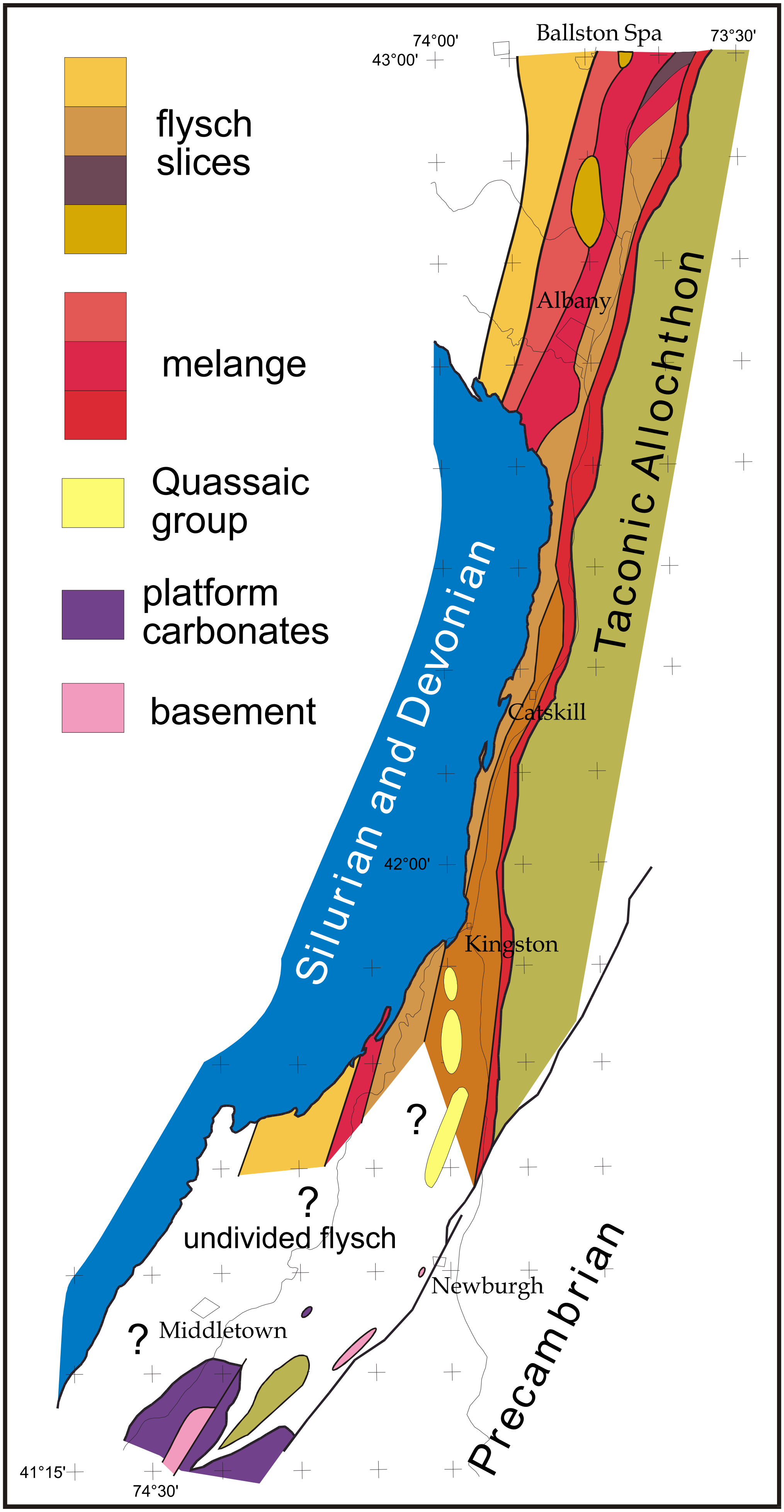


Fig. 88 Summary map of tectonic units in the central Hudson Valley

above. For the northeastern quadrangle the state map (1970) was consulted and three additional outcrops visited: melange at Schaghticoke Gorge (well described in Bosworth 1989), 0.5m thick greywacke beds south of Hansen Rd. ca. 0.5km west of Rt.40 (396) and melange at Buttermilk Falls (302). At Buttermilk Falls good outcrop in the river bed and along the walls exposes a good section of block-in-matrix melange containing one of the largest chert blocks seen (10m*2m). structurally overlying a better bedded section of folded thin bedded greywackes. Further west mainly black shale with minor thin (<5cm) greywacke beds becomes again disrupted and melangy. In the shale section there is a zone of black, fissile, purplish brown-red weathering shale.

Albany

Vollmer's (1981) map and its correlation with this study was discussed previously. The Glenmont chert sliver and the Normanskill melange are not singled out, but have been included into the eastern exotic melange of this study.

Troy

The area in this map sheet south of the area covered in detail by this thesis was mapped by Elam (1960). The chert and carbonate breccia which hold up Grandview Hill and Vandenburgh Hill were included by Elam (1960) into his upper member of the Snake Hill as large slide blocks. As no typical flysch east of those hills was mapped it was preferred to include those localities into the sequence of the Taconic allochthon. This requires a fairly sharp bend in the trace of Taconic Frontal Thrust between east of Ryesdorph Hill and west of Grandview Hill. There is essentially no outcrop at the position of the inferred bend. This allows interpretation of the bend as irregularity in the shape of the steeply dipping Frontal Thrust (chert as hard large asperity above the thrust surface), as offset by a small tear fault or as indication for a gentle dip of the Frontal Thrust. Because the dip of the thrust surface is not expected to change quickly along strike and exposures of the Frontal Thrust in this area show fairly steep dips, the gentle dip option is the least likely.

Coxsackie

Outcrops, structural data and the location of the Taconic unconformity and the Taconic Frontal Thrust are from maps made by the participants of the SUNYA undergraduate mapping course in 1989. Most outcrops show thick bedded greywacke beds. Massive black Mt. Merino chert is found at two localities, Flint Mine Hill (1.5km south of the Coxsackie Prison [Correctional Facility !]) and on the S side of Rt. 28 500m east of Rt. 9W where the road cuts a north-south trending ridge. The hill just west of Flint Mine Hill, which shows up on the base map, is underlain by greywacke (Ruedemann 1942*b*). Melangy shale is rare and found in Coeymans at Coeymans Creek and across the Hudson at Schodack Landing. Together with thoroughly disrupted siltstones and sandstones of Taconic affinity (Rt. 385 south of Athens) these suggest the continuation of the Frontal Exotic Melange which seems to narrow considerably in this area. In general, bedding in the greywackes dips steeply to the east. Behind the Grand Union in

Ravena greywackes are overturned and east dipping. Student mapping documents overturned and west dipping greywackes just west of or at this locality. This indicates either measurement mistakes or complicated structure. The occurrence of a west dipping discrete back-thrust in a creek just south of New Baltimore west of Rt. 61 as mapped by the SUNYA course indicates a perhaps complicated structure in this area. The occurrences of Mt. Merino chert indicates a substantial thrust separating the flysch melange-greywacke slice of mine and Vollmer's field area from a structurally overlying greywacke slice. The chert is thought to have been brought up as a fault sliver under a thrust which joins the main detachment in depth. The main detachment was responsible for most of the transport of the chert. The association with a fault is not only indicated by the allochthonous nature of the chert but also by the stronger deformation of it as compared to the surrounding greywackes. This is best observed at another outcrop of Mt. Merino chert just north of Catskill (see description below), but to a limited extent also at the mentioned locations. The small road cut at Rt. 28 shows a higher degree of fracturing and cleavage and at Flint Mine Hill observation of slickensides and irregular fracturing in loose rocks and in rather unsatisfactory outcrop also indicates a higher degree of deformation. It is assumed that chert occurrences are due to the same thrust because this is the simplest interpretation. If this is the case the trace of the thrust seems to be cut by or perhaps join the Frontal Exotic Melange. Here, as in other places (Troy quadrangle), the cutting option is preferred because the Frontal Exotic Melange is everywhere fairly well defined and is not offset in the vicinity of thrusts approaching from the west of it. Also, these earlier thrusts trend consistently NNE where recognized, a consistency difficult to explain if these thrust were to be seen as mere branches of the Frontal Exotic Melange thrust.

Catskill

Again, the SUNYA mapping course (1989) is the main source of information. Important and visited outcrops are the area of the company Village Oil on the west side of Rt. 9W, 2km north of its junction with Rt. 23 in Catskill, the western approach to the Rip van Winkle bridge in Catskill and a roadcuts on Rt. 23B/9G and Rt. 23 close to their junction east of the Rip van Winkle bridge (fig. 89). The Taconic Frontal Thrust - the contact between the Cambro-Ordovician Taconic sequence and Medial Ordovician flysch and melange - and the Frontal Exotic Melange are fairly well defined in the northern quarter of the quadrangle. The Taconic Frontal Thrust is actually exposed in the long road cut on Rt. 23B/9G. At the southwest end of the outcrop black shale has zones of phacoidal cleavage where the shale contains exotic material namely greenish shale and cherty blocks. Foliations are steeply dipping to vertical. The contact to the Taconic sequence rocks to the northeast is marked by the broadest of these zones, is sharp and is essentially vertical as well. Bedded black Mt. Merino chert at the contact is tightly zig-zag folded with a wavelength of about 5m and a steeply dipping axial plane at an high angle to the contact (fig. 90, 91). The chert is juxtaposed by a steeply dipping fault with a less deformed, moderately-dipping. long continuous section of Taconic strata in the northeast part of the road cut, also containing Mt. Merino chert structurally at the top. A nearby roadcut at the south side of Rt. 23 at its junction with Rt. 23B/9G exposes massive, well bedded, gently east dipping, unfolded ca. 10m thick Mt. Merino chert in its eastern section (fig. 92). It is underlain by less well exposed, ca. 3m thick papery, black sooty shale which turns to the west into grey shale and bedded, thin greywackes

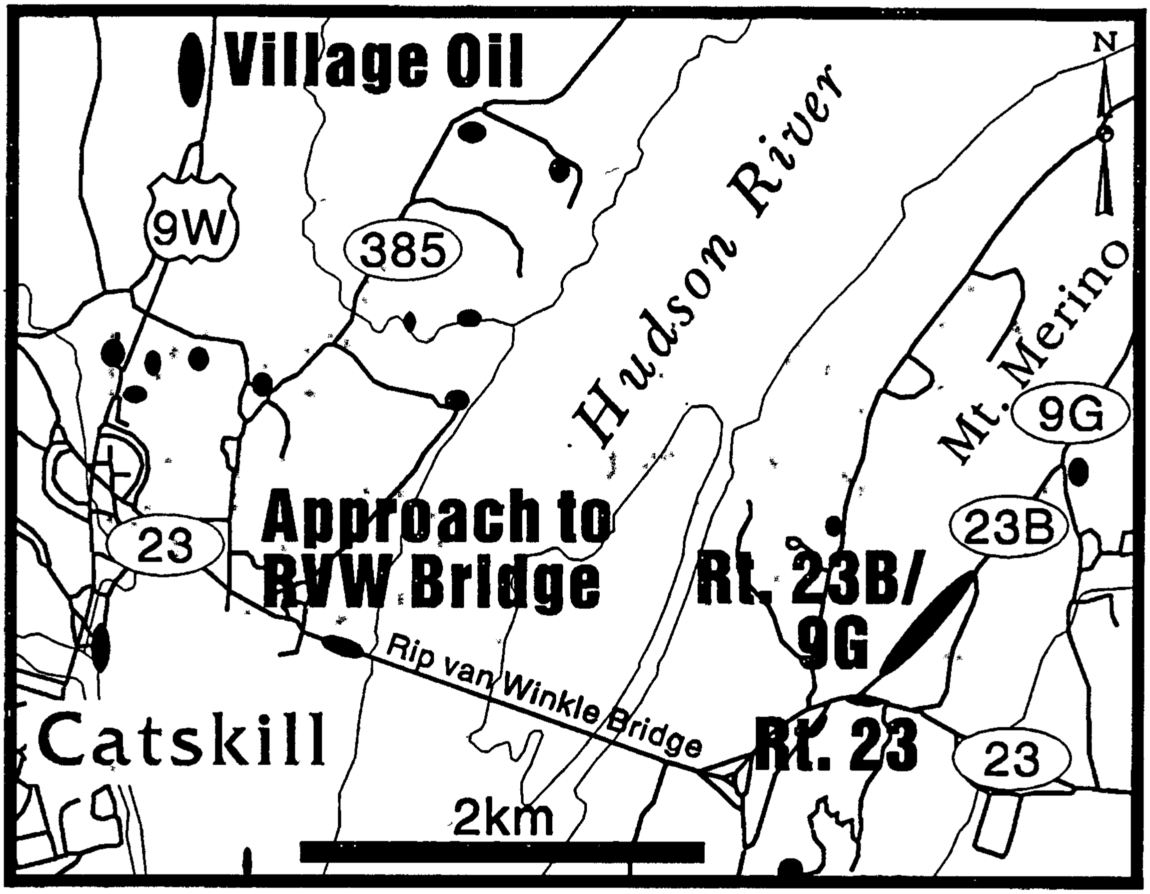


Figure 89 This road map in the Catskill area shows the location of some important outcrops. Some geographic features are named. Outcrop references as used in the text are in large bold letters.

Figure 90 Taconic Frontal Thrust juxtaposes Mt. Merino chert (center and right) and phacoidally cleaved shale including small blocks (left). The person located adjacent to the contact is Bill Kidd. NW-cut Rt. 9G, Mt. Merino.

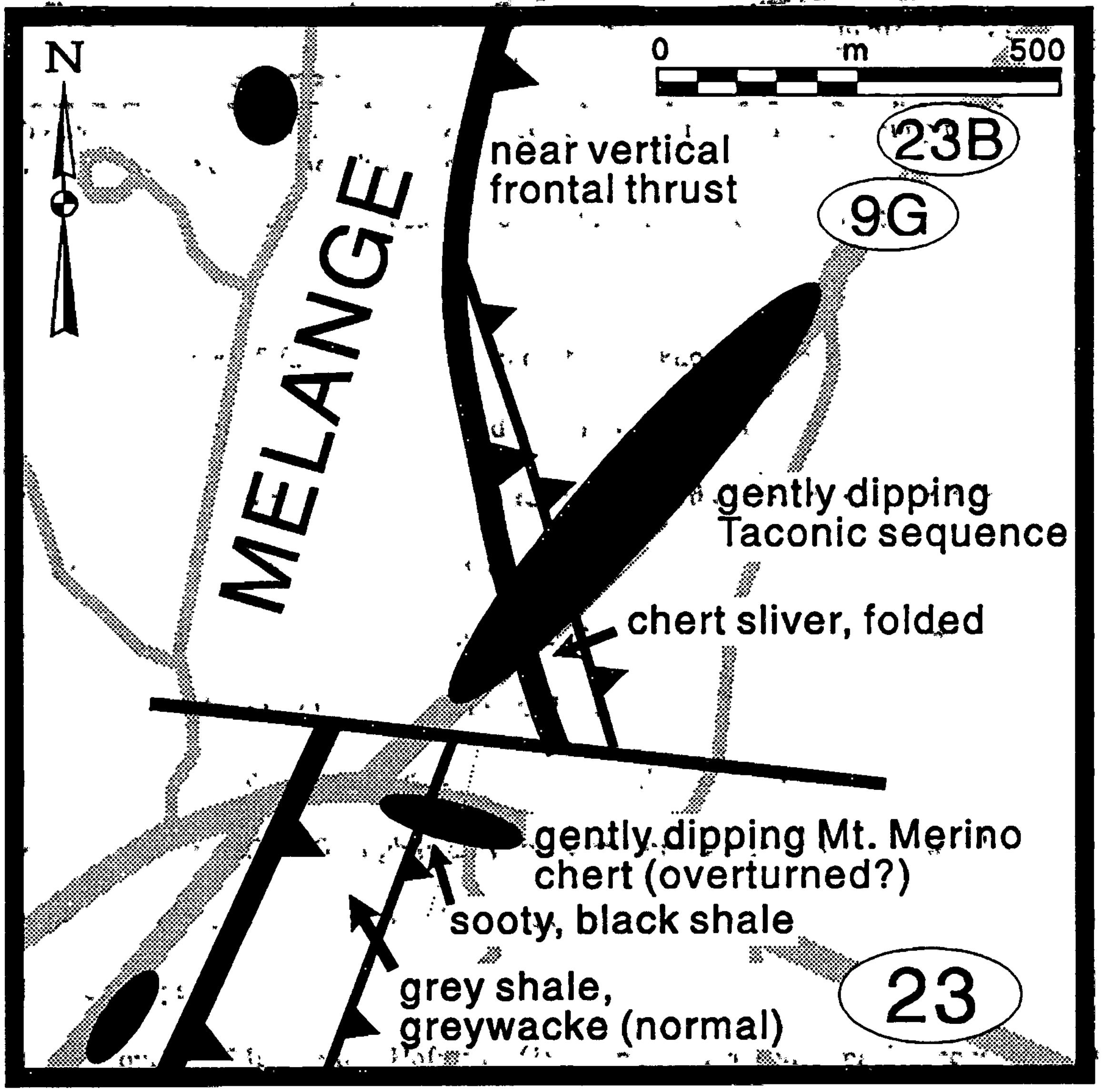


Figure 91 This simplified geologic map of the Mt. Merino area shows the main outcrop observations and the resulting geologic interpretation. Black ellipses inidicate outcrop.

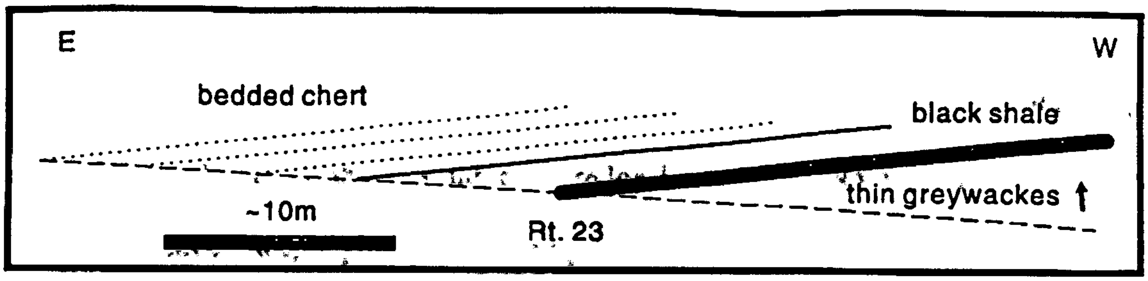


Figure 92 Contact relations at Rt. 23 close Rt. 9G. Arrow indicates younging, bold line is thrust. See text for brief discussion.

(ca. 2m exposed). A thin sandstone bed yielded there bottom structures indicating a normal sense of bedding. The sharp contact between chert and black shale does not show obvious evidence of faulting. Mt. Merino chert is known from other localities in the Taconic Allochthon (Rowley and Kidd 1981) to be underlain by green and red Indian River slates and never by thin greywackes. Therefore the western shale and greywacke of the outcrop is likely to be in thrust fault contact with the papery, black sooty shale. It is hard to find younging indicators in this black shale or in the massive chert which was affected strongly by diagenetic effects. It cannot be decided if the black shale stratigraphically underlies or overlies the chert. Rowley, Kidd and Delano (1979) mention "coal black, generally soft, slightly silty, rusty to white weathering slate" which overlies in places the Mt. Merino cherts. Fig. 91 shows a possible map pattern for the area of these outcrops.

South of Mt. Merino Hofmann (1986) mapped a conformable sequence a of Taconic sediments along a ridge just east of the Taconic Frontal thrust (pers. communication Kidd).

For lack of information to the south it is assumed that the Frontal Taconic Thrust and Frontal Exotic Melange just continue in the direction of the regional strike. The few reported outcrops of Taconic lithologies and greywackes are consistent with this assumption.

In the greywacke slice to the west bedding often dips steeply east. In the better exposed Catskill area north and south dips are locally reported. No west dipping beds are seen in this slice. Steeply plunging fold hinges and a melange occurrence indicate a high degree of internal deformation and thrusting. The road cut at the western approach to the Rip van Winkle bridge represents the longest exposed section across the regional strike in this slice and is therefore described. The northern cut is longer and more instructive than the southern cut. Most structures cannot be traced across the four lane road. East of an isolated, approximately horizontal thick greywacke bed a large fold hinge of an inclined anticline with a moderately east dipping axial plane marks the western limit of the outcrop. Closer inspection of the thin (< 30cm) greywackes of the eastern limb of the anticline reveals small scale imbrication (figs. 93, 94). About six well defined narrow thrusts can be identified which dip slightly more steeply east than bedding, or follow bedding planes. Thrusts are identified where they climb and bedding is truncated. A small anticline near the center of the outcrop is associated with a thrust. A thick greywacke bed at the east end of the outcrop seems to localise the thrusting under it. The structural thickness of the individual thrust slices is between 1m and 5m.

This eastern greywacke slice is separated from an western greywacke slice by a thrust which brought up non-flysch lithologies recognized at three locations. Two of those are in the Coxsackie quadrangle, the third just at the northern limit of the Catskill quadrangle on the west side of Rt. 9W, ca. 2km north of Catskill in the area of the company Village Oil (fig. 95). The outcrop exposes mostly blue-green chert, but also greenish siliceous shale, pale green shale and little purple weathering grey-green fine

Figure 93 East dipping turbidite bed is duplicated by imbricate thrusting. Bedding is truncated above upper fault block as well (Rte 23, western approach to Rip van Winkle Bridge, north cut).

Figure 94 Truncation of bedding shows thrusting. Central greywacke slab is bound on all sides by thrusts (horse). Rte 23, approach to Rip van Winkle Bridge, north cut. Photograph by Bill Kidd.

Figure 95 Disrupted chert at Company Village Oil (west of Rt. 9W, 2 km north of Catskill. Looking north.

Figure 96 Preserved bedding in chert (left of hammer) is truncated by fault zone of cleaved, green shale juxtaposing massive black chert.

grained greywackes. The chert often has a purple pyrolusite stain indicating a manganiferous composition. The green siliceous shale displays small, reflecting, sand-sized particles dispersed on fracture surfaces, probably radiolaria. This property is also described from the Indian River Formation (Rowley 1983). The degree of disruption in the outcrop is high, in fact it is difficult to find bedded sections thicker than ca. 1m (fig. 96). Melangy sections are about 2m thick. Foliations dip generally steeply to the east. Two measured attitudes of bedding are 050°/85°E and 020°/62°E. Phacoidal cleavage in shale dips in one place 85° to the south striking 070°. No eastern or western contact with greywackes is exposed.

To the south no outcrop exposes non flysch lithologies or melange associated with this substantial thrust in this quadrangle and it is speculated that it - having a steep dip - does not change strike significantly and disappears under the Hudson River not far south of Catskill.

The greywacke slice to the west of this thrust is exposed by only a few outcrops. Bedding dips except for a few cases moderately to steeply to the east like in areas to the north. Large scale folding of the Taconic unconformity at the base of the Devonian Helderberg Group carbonates is demonstrated by its trace recognized from outcrops and the escarpment it usually produces. The north-south striking Great Vly is at the position of the fold axis of the anticline in the "N" shaped (cross-section looking north) Great Vly fold. The Siluro-Devonian core of the Great Vly syncline builds a recognizable outlier in the Medial Ordovician greywackes. Opposing younging directions in the greywackes to either side of the fold axis of the Great Vly anticline are found to the south of the outlier and are thought to result from this folding. Bedding of the greywackes must have been re-rotated by this late folding. Greywacke beds in the eastern limb of the Great Vly fold southeast of the southeastern corner of the Devonian synclinal core dip steeply east. They do not show the expected rotation from an original moderate to steep eastern dip to a gentle east-dip. The most reasonable conclusion from this apparent lack of observable rotation is that the post-unconformity folding was mild.

Marshak (1986) studied in detail deformed Devonian rocks west of Catskill. Outcrops along Rt. 23 expose nicely post-Taconic folds and thrusts. Marshak describes many structural features typical of fold and thrust belts including bedding parallel thrust, ramps, duplex stacks, out-of-the-syncline thrusts, back-thrusts, ramp anticlines or fault propagation folds. The whole area was affected by mild late large scale folding with wavelengths between 200m to 800m. This mild folding is probably associated with a detachment in depth, possibly a reactivated Taconic detachment. The main Acadian detachment, which is affected by the mild large scale folding and accommodates the overlying thin-skinned deformation, is found just above the Taconic unconformity. Cumulative displacement is between 0.5km and 1km in the exposed westernmost 3km of the Hudson Valley fold and thrust belt judging from carefully constructed cross-sections (Marshak 1986). Interestingly, the observational data were dense enough to propose that good length balancing of a cross-section which is consistent with outcrop observations is not possible due to mesoscopic and internal strain. Marshak (1986) suggests specifically that maximum offset on faults above the Taconic unconformity is less than a few hundred meters because nowhere is repetition of units observed over a significant length and Ordovician rocks are never emplaced above Devonian rocks.

Stereoplots of poles of bedding and trend and plunge of fibers in the Devonian show a fairly well defined average strike of 020° for bedding and a less well defined average trend of 105° for the fibers (Marshak 1986). Typically post-Taconic structures between Catskill and Kingston strike 000° to 015° (Marshak and Tabor 1989).

Rhinebeck

The SUNYA mapping (1989) covered an area to the latitude of Kingston. Locations of outcrops south of Kingston in the Taconic allochthon are from Fisher and Warthin (1976). Cunningham (1987) describes outcrops along the Hudson River at the southern limit of the Quadrangle. Waines (1986) summarizes results of student mapping in the northern Marlboro Mountains (Quassaic Group).

The Taconic Frontal Thrust and Frontal Exotic Melange are not exposed. The few outcrop locations retrieved from publications define the contact of Taconic rocks and flysch only loosely. It is assumed that the nature of this contact does not change. The Frontal Exotic Melange is thought to be continuous because rocks indicative of this melange reappear further south (Poughkeepsie). The lack of observation of such a melange is more likely due to poor outcrop and insufficient mapping than due to its nonexistence.

The flysch slice to the west can be traced from the Catskill quadrangle through the Rhinebeck quadrangle as well. Bedding strikes mostly N to NNE dipping moderately to the east. Dips do not exceed 60° in the Kingston area. Cunningham (1987) reports some outcrop descriptions from outcrops of greywacke, siltstone and shale along the Hudson River at the southern limit of the quadrangle. He describes similar attitudes of bedding and abundant isoclinal folding and thrusting. He also reports greywacke-blocks-in-shale-matrix melange and phacoidal cleavage in restricted zones. These occurrences at the southern limit of this sheet indicate another major thrust which separates flysch slices. It is thought to be cut across the river by the Frontal Exotic Melange.

Occurrence of melange is reported just north of Kingston close to the Taconic unconformity (SUNYA mapping 1989). The melange is thought to be related to the major thrust juxtaposing an eastern greywacke slice against a western one because it projects into the occurrences of exotic lithologies ca. 30km to the north and because a single major thrust can explain best the rareness of outcrops of melange and exotic lithologies in this area of well bedded greywackes and shale.

A sharp topographic break in form of well defined ridges clearly marks the contact between the Medial Ordovician greywacke turbidites and shale and the Quassaic Group sediments. The coarse fraction of the Quassaic Group sediments is usefully distinct from the adjacent greywackes; the massive-appearing, sometimes conglomeratic and very coarse arenites and associated clastic sediments have sufficient areal extent and homogeneity to warrant the establishment of their own name. This was recognized by several workers (see Waines 1986). Sedimentologically, the Quassaic clastics can be classified as marine molasse facies deposited in a lower to upper slope deltaic environment (Waines 1986). Fisher (1977 *in* Waines 1986) correlated conglomerate clasts, including carbonates, with Taconic lithologies of slope/rise affinity (see also Bird, *in* Bird and Dewey 1970).

Whereas the distinctiveness of the Quassaic Group is well established, its relation to the surrounding Medial Ordovician flysch is less well known mostly because of lack of exposure. The relative age is critical for this relation. Contacts are not exposed and fossils are rare. A few specimens of the gastropod ***Cyclonema bilix*** were found in the Quassaic which may indicate a Late Ordovician (Richmondian) age (Waines 1986). Waines (1986) is mostly concerned about the internal stratigraphy of the Quassaic Group sediments, so he does not report in detail structural aspects of mapping and field investigations which may help to constrain the relation between the distinct Quassaic sediments and their surroundings. Steeply east or/and west (unclear) dipping, sometimes overturned beds along the (best exposed) eastern margin of these sediments apparently differ in their attitude from beds to the west (Waines 1986). Waines (1986) proposes a syncline as the fundamental underlying structure, following Rickard (1973), apparently based on this dip difference, the younger relative age, and repetition of marker beds. Structural data are not provided. Kalaka and Waines (1987) mention SE-dips in bedding east of New Paltz, but apparently in flysch and not in the Quassaic. As no structural data are provided and none of the arguments seem particularly convincing this proposal remains largely speculative. The eastern limit of the Quassaic Group is described as a steeply east dipping reverse fault unfortunately without giving a justification of its nature (Waines 1986). Cunningham (1987) who mapped in the Poughkeepsie area describes this contact as a thrust fault without defining its dip. Given the abundance of faults in this belt in general, and the sharp nature of the contact expressed in the topography, a tectonic contact is expected. The dip of this fault is not obvious and its sense doubtful as it could only be inferred from rather uncertain relative ages.

Concerning the large scale structure two observations are the most interesting. First, the Quassaic Group sediments separate heavily deformed and disrupted shales and siltstones to the west from strongly folded and faulted greywackes and shales in the east. Citations of formation thicknesses from within the Quassaic Group (Waines 1986) indicate fairly intact sections. However, insufficient outcrop and less distributed faulting in the often massive arenites of the Quassaic Group may have prevented identification of major faulting. In fact, to the south where an unmodified syncline model apparently does not explain the observed outcrop pattern, Waines (1986) recognizes a thrust which he interprets as an out-of-the-syncline thrust. Second, outcrop of Quassaic and topography defines a 40km long north-south striking structure, oblique to the regional strike in the greywackes and melange of 020°.

The threefold west-east succession of strongly deformed shale and siltstone, possibly less deformed and younger massive Quassaic sediments and strongly deformed greywacke turbidites and shale may indicate that there are three individual tectonic units or thrust slices. In this case the Quassaic could be the same age or older than the western shaly flysch facies or the western contact might be modified by later backthrusting or normal faulting. The obliqueness of the whole structure indicates that the boundary defining deformation may have occurred later than the main deposition or emplacement.

The distinct sedimentary facies indicates deposition in a specific sedimentary environment, possibly a piggyback basin (Ori and Friend 1984) above flysch basement. A piggyback basin is suggested by the age possibly younger than flysch (early late Ordovician) for the Quassaic, and its position within allochthonous flysch. Applying the tectonic model derived for my mapping area implies that the flysch is allochthonous because the trace of the basal detachment projects further west. Lash (1990) bases his identification of such an early late Ordovician piggyback basin in southeastern Pennsylvania, the Shochary Ridge sequence, on distinct sedimentology and palinspastic restoration.

The north-south orientation of the hills underlain by the Quassaic may be correlated with the general north-south trend of structures within the Devonian sediments to the north (Tabor and Marshak 1989). The post-Taconic Hudson Valley fold and thrust belt projects directly into this series of hills. Therefore post-Taconic thrusting could be responsible for the oblique trend of the Quassaic.

Rosendale

Outcrop locations and structural information were extracted from Epstein and Little (1987), Kalaka and Waines (1987) and Waines (1986). One outcrop 1.1km ESE of Mohonk Lake (stop 1 of Epstein and Lyttle 1987) was visited.

The western contact of Quassaic Group sediments with Medial Ordovician shales and siltstones (Kalaka and Waines 1987, Epstein and Little 1987) is less distinct than the eastern contact. Waines (1986) includes what from his description appears to be usual Medial Ordovician flysch in his Quassaic Group sediments based on a tentatively identified graptolite species (***Diplograptus recurrens***) indicating an early late Ordovician age and a slightly higher turbidite influx, and claims a conformable nature of the contact in an upward coarsening section. The line on my map separating Quassaic from western flysch does not follow this suggestion because it is likely that the area is structurally complex. I use a phenomenological (non-interpretative, less inferrential, more descriptive) distinction only based on clear lithological differences, and the boundary was drawn to separate typical; massive, often coarse, conglomeratic, sometimes red-clast containing and crossbedded Quassaic sediments from flysch, by utilizing information in Waines (1986) and tracing topography.

The major thrust which was traced from the Coxsackie Quadrangle through the Catskill Quadrangle and the Rhinebeck Quadrangle disappears under the Taconic unconformity and is thought to reappear south of the Siluro-Devonian cover. No direct confirmation of this continuation could be established. Consistent with the trace of this thrust is a boundary between more hilly terrane to the east and flat terrane to the west indicating perhaps juxtaposed greywacke-rich and shale-rich domains. Also consistent with the trace of this thrust is a contrast in the mesoscale style of deformation in structural domains as reported by Kalaka and Waines (1987). Kalaka and Waines (1987) include most of the area between Mohonk Lake and New Paltz in a structural domain which is characterized according to them by a complex style of mesoscale folding and imbrication by east-dipping thrusts. They do not give a more detailed description. East of New Paltz they report SE-dipping strata apparently without major mesoscale deformational features.

The visited locality near Mohonk Lake ca. 20km west of the Taconic Frontal Thrust exposes one of the best examples in this area (Epstein and Lyttle 1987) of well developed phacoidal cleavage in shale and greywacke block in shale matrix structures. The fairly narrow melange zones alternate with well-bedded thin greywackes (< 10cm) and shale. Dips change from gently east dipping to nearly vertical. The broadest melange zone (width ca. 3m) contains slab shaped greywacke blocks.

The Silurian cover in the Mohonk Lake area is generally only gently dipping and cut by small thrust faults (Epstein and Lyttle 1987). In the vicinity of the Taconic unconformity it is in principle possible to distinguish between Taconic and post-Taconic faulting by tracing thrusts into the Silurian cover. Epstein and Lyttle (1987) mapped the Mohonk Lake area in detail and found that melange type thrusts are Taconic in age whereas discrete thrusts, often accompanied by bedding parallel veins and penciling, and striking a little more northeast in this area, are post-Taconic. By reconstructing cross-sections across the Taconic unconformity from northern Pennsylvania to southern New York Epstein and Lyttle (1987) try to evaluate the importance of post-Taconic deformation. They conclude that large scale post-Taconic deformation decreases substantially to the north and that at the latitude of New Paltz (by considering the Ellenville arch ca. 7km west of Mohonk Lake) the unconformity was only mildly folded. Although some post-Taconic thrusting, and not only mild folding, was mapped at Mohonk Lake, the unambiguous general trend of decreasing post-Taconic deformation at a larger scale makes it clear that also at Mohonk Lake post-Taconic deformation was mild. The post-Taconic thrusting is likely to exhibit only minor displacements perhaps in the km range.

Poughkeepsie

Gordon (1911), Fisher and Warthin (1976) and Cunningham (1987) provide primary information. Three outcrops were visited, all in or close to Poughkeepsie. A roadcut in Poughkeepsie located north of the railroad bridge and between the Hudson River and the railroad tracks off Water St., ca 1km north of the Kaal Park locality under the Mid-Hudson Bridge (Fisher and Warthin 1976) displays melange with a good chaotic block-in-matrix structure. Shale is phacoidally cleaved. Besides greywacke blocks (<1m) non-flysch lithologies were also noted, particularly sideritic mudstones. At the Kaal Park locality which also exposes good melange, blocks are "almost exclusively Austin Glen graywacke" (Fisher and Warthin 1976). A photograph of this melange (*in* Fisher and Warthin 1976) shows an unusually high density of blocks. As, east of these outcrops, larger coherent pieces of Taconic lithologies are found (Fisher and Warthin 1976) this melange is thought to be related to the Taconic Frontal Thrust and equivalent, in fact identical, to the Frontal Exotic Melange of my detailed field area.

Fisher and Warthin (1976) show a map which indicates low angle contacts including the Taconic Frontal Thrust. Large areas to the east are depicted as greywackes not belonging to the Allochthon. Unfortunately it does not show outcrop locations. Therefore one is forced to use personal judgement and common sense to evaluate the map. It is felt that instead of a complicated wavy line (implying a subhorizontal fault) as in Fisher and Warthin (1976) also a simple straight line can be used to separate the Taconic lithologies from flysch to the west. This is apparent even from Fisher and Warthin's (1987) map if one keeps in mind that poor outcrop and structural complexity effectively restrict demonstration of detailed traces of boundaries. One is left with a two part division between monotonous greywackes and shale to the west and Taconic lithologies to the east. The line representing the Taconic Frontal Thrust on my map follows this division. Austin Glen greywacke is known to occur at the top of the Taconic sequence in places (Rowley and Kidd 1981) which could explain occasional occurrences of Austin Glen greywacke within the Allochthon as indicated on Fisher and Warthin's (1976) map.

Non-flysch lithologies were also visited at Blue Point (Cunningham 1987) at the western Hudson shore 2.7km south of the Mid-Hudson Bridge. Monotonous bright green slate is strongly foliated. Bedding can still be recognized and dips gently west into the outcrop. The strong foliation dips moderately to steeply east. North of this outcrop along the Hudson shore folded and faulted greywackes and shale are exposed in a series of outcrops (Cunningham 1987). The contact between the strongly foliated green shale and the greywackes is partly exposed (fig. 97). At the northern end of the outcrop the strongly foliated green shale is sharply juxtaposed to a ca. 1m wide zone of black, strongly deformed shale by a southeast dipping fault. North of a small covered stretch, bedding in bright grey siltstones and shales strikes 045° and dips 76°. This bright grey siltstones and shales show a weak s_1 cleavage which strikes also 045° and dips 60° to the southeast indicating possibly overturned beds. The bedded bright grey siltstones must be separated from the strongly deformed black shale by a fault. Bright green shale or slate occurs in the southern Taconic sequence in several formations (Fisher and Warthin 1976). Based on the association of similar pale green shale or slate in assemblages of non-flysch lithologies in melange elsewhere it is speculated that the strongly foliated bright green slate correlates with the youngest of those Taconic formations, the Indian River Formation. The black shale is typical for shaly parts in the Mt. Merino which overlies the Indian River (Fisher and Warthin 1976). The bright grey siltstones and shales are probably thin turbidites and belong to the medial Ordovician Austin Glen greywacke. Based on these data the contact is interpreted as a thrust fault, in which a small fault sliver of Mt. Merino black shale was caught during transport. This interpretation is consistent with the observed sharp contact, the differing degrees of foliation development and deformation, and the inferred stratigraphic relations. Although no melange fabrics were found, the outcrop is still included in the belt of the Frontal Exotic Melange because of its sharp contrast with the greywacke turbidites to the west and its location along strike from the melange exposures in Poughkeepsie. The foliated bright green slate is thought to be a larger slice in the melange located at the base of the melange in contact with the

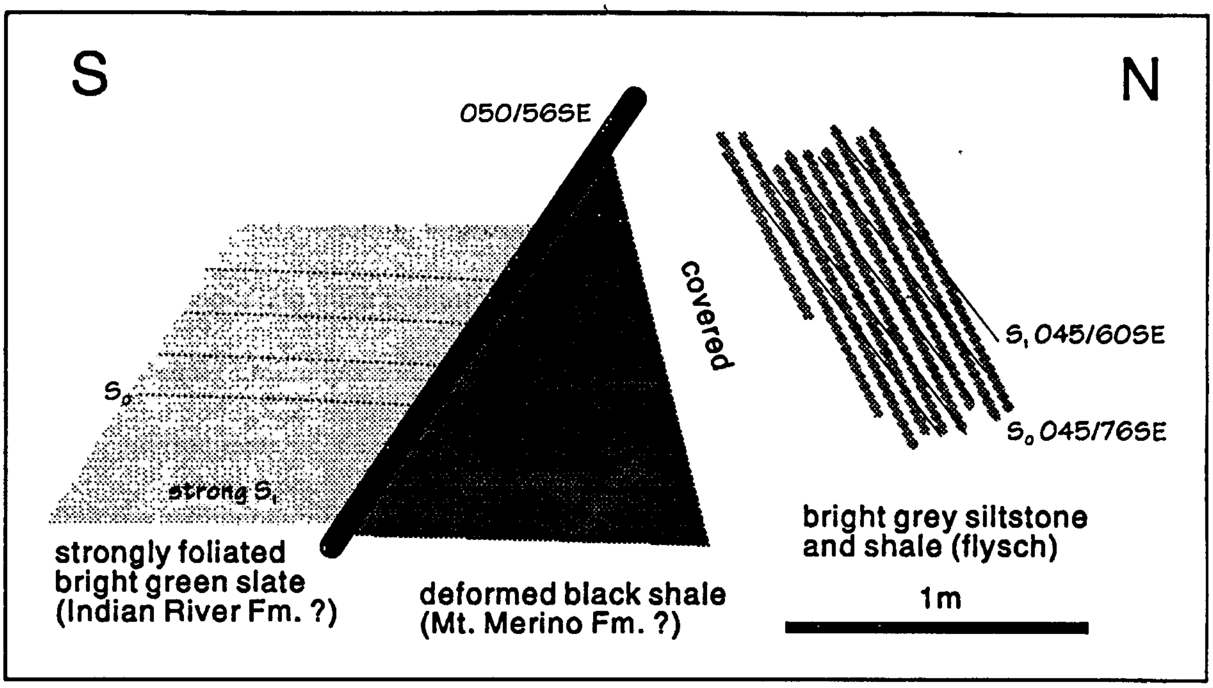


Figure 97 At Blue Point, Poughkeepsie, 2.7km south of the Mid-Hudson bridge on the western Hudson shore, the tectonic contact between strongly foliated bright green slate and bright grey flysch is marked by a sliver of black shale.

greywackes to the west.

The Frontal Taconic Thrust and the Frontal Exotic Melange cannot be traced much further south and are probably cut by a late ca. 030° trending fault system which carries Taconic sequence rocks including Mt. Merino chert and Austin Glen greywacke as well as basement in the south and is clearly marked by a topographic lineament.

The most extensive exposure of massive Medial Ordovician greywackes in the Hudson Valley is the western approach to the Mid-Hudson Bridge, Rt. 44 (fig. 98). Turbidites are up to 2m thick and interlayered with thin, compact, not obviously laminated dark black shale probably containing a high amount of organic matter. This indicates a pelagic environment of deposition. Only the thickest beds are fairly coarse grained. Among the sedimentary features which can be studied are beds which are crossbedded on a dm scale cutting into isotropic turbidites, leading to amalgamation. This indicates strong bottom currents which redistributed sands, that were originally deposited by turbidites. Bedding dips moderately to the west and is steeper towards the bridge. A measured attitude of bedding at the west end of the outcrop is 020°/32°W. Cleavage is developed in finer grained sections and is dipping gently east. A measured value at the same position is 010°/10°E. This gentle dip of the cleavage provokes some thought. Provided it developed by some pressure solution process, e.g. as fold axial planar cleavage, it is likely that it had originally a steep dip as compressive stresses were probably more or less horizontal. Then a second stage rotation becomes necessary and a more complicated deformational history likely. Perhaps the cleavage formation stage and the rotation stage can be attributed to Taconic and Acadian (or Alleghenian ?) deformational events respectively. Slickensided and often bedding-parallel detachments are not uncommon, and

Figure 98 Faulting and folding in interbedded turbidites in north cut of western approach to mid-Hudson Bridge, Poughkeepsie (photograph by Bill Kidd).

become more pronounced and narrower spaced towards to the bridge. Intact conformable sections probably do not exceed 15m stratigraphic thickness. Slickensides on one gently west-dipping fault trend 120°.

Cunningham (1987) describes ca. 30 outcrops along the Hudson shore from the mentioned outcrop at Blue Point north into the Kingston Quadrangle. Overturned beds, plunging folds, bedding parallel slickensided detachments and thin melange fault zones are found frequently and demonstrate a complex style of deformation. From the semiquantitative description of structural attitudes in Cunningham (1987) it appears that bedding strikes mostly between north and northeast and dips preferentially at no discernable favourite angle to the east although west dips are not uncommon. Cunningham (1987) identifies a less complexly deformed stripe of greywackes between the Hudson River and the Quassaic Group sediments of Illinois Mountain to the west. According to him most of the beds are slightly overturned striking between 000° and 010° and dipping 80° to 87° E and the rarer upright beds dip gently 20° to 30° E. Unfortunately Cunningham (1987) makes no effort to evaluate the degree of interpretability, for example by indicating the location and distribution of outcrops. Therefore it could be possible that the "recognition" of this less complexly deformed stripe is just the result of insufficient outcrop as compared to the almost continuous outcrop along the Hudson shore.

Gordon (1911) provides no substantial additional information and was used mainly as a source of outcrop locations.

Newburgh

Holzwasser (1926), Waines (1986), Kalaka and Waines (1987) and Epstein and Lyttle (1987) were utilized in the compilation process.

One small roadcut on Rt. 17K was observed just west of Newburgh which displayed thin greywackes (<2cm) and shale with good slaty cleavage.

Most bedding attitudes given on the map were measured by Holzwasser (1926). Only the outcrop locations decorated with such data were copied onto my map assuming that those are the larger and more likely preserved ones. She indicated on her map significantly more, not measured outcrops mostly surrounding in groups the measured ones. The late 030° trending thrust reappears on her map in the southeastern corner. The outlier of basement and conformably overlying quartzite and carbonate just west of Newburgh is thought be produced by this thrust.

Rocks in the Wallkill "valley" cover the whole range of flysch sediments (Kalaka and Waines 1987). Shale and siltstone dominate over the rare thicker greywacke beds. Kalaka and Waines (1987) distinguish a shale rich zone east of the Wallkill (their Bushkill Shale) from thick greywacke-bearing zones west of river (their Pen Argyl and Ramseyburg equivalents). They describe the Pen Argyl equivalent and Ramseyburg equivalent as very similar.

Marlboro Mt. and its northern continuation represents the southern continuation of the Quassaic sediments and is held up by steeply dipping to vertical beds. It is separated by a valley from a 015° striking series of hills which appears to be cut or joined to the north by the north-south trending Quassaic. The tectonic significance of these relations is unclear.

Bedding strikes with only a few exceptions NNE and dips moderately east. Two occurrences of west dips are reported and four instances of steeply dipping or vertical strata (east of Montgomery and south of Walden in the southwest corner of the quadrangle and in New Paltz at the northern limit). Holzwasser (1926) draws a line indicating a probable fault at the location of the southern extrapolation of the major thrust traced from Flint Mine Hill in the Coxsackie quadrangle to the south. She seems to use a north-south trending series of hills from a village called Flint at the center of the quadrangle down south to the vicinity of Coldenham (Racoon Hill, Kings Hill, Breakneck Mt.) as a guide for the trace of the fault. Only the southern half of this range shows in the obliquely illuminated DEM, the topographic background of my map.

Another major thrust is reported by Lyttle and Epstein (1987) and Kalaka and Waines (1987). It is named Ganahgote fault and follows approximately the Wallkill river. Three pieces of evidence are mentioned: an abrupt contact of tectonic domains, data from the Delaware Aqueduct and exposures of a fault zone on Rt.44/55 near Ganahgote and of nearby unusually thick and overturned greywackes in the Shawangunk Kill. Based on penciling associated with thrusts observed in the roadcut - a feature Lyttle and Epstein (1987) found to be characteristic of post-Taconic faulting in mapping the Taconic unconformity in the Mohonk Lake area - they conclude a post-Taconic age of the Ganahgote fault zone. However, there is also evidence for a Taconic age of thrusting. Epstein and Lyttle (1987) report two ages of slickensides. Early slickensides are folded and are older than the slickensided faults associated with penciling. Also the separation of structural domains (Epstein and Lyttle 1987, Kalaka and Waines 1987) cannot be traced into Silurian cover. Integrating these arguments a reactivated major Taconic thrust is proposed. Whereas Taconic, possibly more distributed thrusting lead to the principal juxtaposition of flysch slices, probably including the emplacement of the unusual thick greywackes in the Shawangunk Kill, later post-Taconic thrusting accentuated the contacts by removing the perhaps once broader fault zones. The proximity of Taconic thrusts and post-Taconic thrusts in the Mohonk Lake area supports this proposal.

Epstein and Lyttle (1987) recognize three Taconic tectonic zones from compilation of geology in the Delaware and Catskill aqueduct tunnels and comparison with surface exposures. The zones strike ca. 010° to 020° and become structurally more complex to the east. The approximate boundaries are indicated on the compiled map as faults. The boundary between the western zone characterized by broad open folds and the intermediate zone characterized by tighter folding and some faulting is in the Ellenville Quadrangle ca. 7km east of Ellenville. The boundary between the intermediate zone and eastern complexly deformed zone characterized by steep dips, overturned folds and melange coincides with the Ganaghote fault zone. This succession of tectonic zones correlates well with the results of Vollmer's (1981) and my work in the Albany area. The western zone corresponds to the Undeformed Flysch of my detailed area, the intermediate zone approximately to the Folded and Faulted Flysch and the eastern zone approximately to the melange dominated eastern part. The good alignment of these corresponding areas in ca 020° trending belts and tracing of these belts in the aqueduct tunnels in part under the Siluro-Devonian cover are good evidence for a Taconic age of the formation of these belts and only minor post-Taconic tectonic adjustments.

The main basal detachment responsible for the emplacement of slope-rise lithologies and flysch onto the carbonate shelf is thought to reappear from under Silurian cover somewhere in the intermediate zone or perhaps near the Ganaghote fault zone.

Ellenville

Only very little geologic information could be found. The only primary source of information was Epstein and Lyttle (1987).

In the core of the Ellenville arch south of Ellenville, a northeast plunging mild post-taconic fold with a half wavelength of about 6.8 km, and along the Taconic unconformity to the east medial Ordovician flysch is exposed. In the Ellenville area enough information is available to reconstruct Taconic folds by unfolding. Epstein and Little (1987) arrive at a broadly open Taconic syncline.

Epstein and Lyttle (1987) also describe a ca. 1km long roadcut on Rt. 17 near Wurtsboro at the Taconic unconformity. Mostly Medial Ordovician flysch is exposed containing shale, siltstone and greywacke in various proportions. At the western limit the unconformity and the overlying Silurian Shawangunk can be observed. Sedimentologically most interesting is a 13m thick olistostrome near the Rt. 17K overpass. Bedding dips gently to the west. The greywackes and shales are cut by a number of faults in a 200m interval. The most obvious fault zone within this interval has an east over west thrust sense. Its associated structures strike more to the north than bedding in the overlying Silurian cover, and in Silurian rocks comparable faulting is not seen. This suggests a Taconic age for these thrusts ca. 40km west of the Taconic Allochthon.

Two roadcuts on Rt. 17 between its junction with Rt. 17K and Middletown were visited. The outcrops display interbedded thin greywacke beds and shale. Sharp erosive bases of the greywacke turbidites show winnowing of the underlying shale.

At both outcrops the main structure is a broad anticline with a more or less horizontal eastern limb and a moderately west dipping western limb. An approximately horizontal hinge line trends 050°. Axial planar cleavage is well developed, especially near the axial plane. Bedding parallel slickensided detachments are fairly frequent. Measured trends of striations are 120° and 130°. The opening direction of accompanying en echelon veins indicate an east over west thrust sense. The folds are thought to be the surface expression of blind thrusts terminating at depth.

Port Jervis

West of Otisville a classic locality (an abandoned rail road track) exposes the Taconic unconformity (stop 5 of Lyttle and Epstein 1987). The unconformity is marked by an up to 30cm thick unlithified zone. Within this zone there is colluvial gravel containing clasts of now not locally available lithologies and disorientated clasts of slickensided vein quartz. This is indirect evidence for Taconic faulting in the nearby flysch. There is also gray clay gouge with slickensided quartz veins within the zone at the unconformity demonstrating later utilisation of the unconformity as a fault zone. From the overlying Silurian Shawangunk no faulting is reported.

Within Otisville a railroad track exposes a recumbent syncline with a gently east dipping axial plane. The overturned limb is cut by minor thrusts. Axial planar cleavage is well developed. The fold axis trends 010° into the unfolded overlying Silurian demonstrating a Taconic age for the fold and probably the faults.

Goshen

The Goshen 15'-quadrangle was mapped thoroughly by Offield (1967). Two roadcuts on Rt. 17 in the vicinity of Chester were visited.

Offield (1967) divides the flysch in the area in three units according to greywacke turbidite frequencies and thicknesses. A flysch unit with some greywacke in the northwest corner of the sheet grades into greywacke rich unit which is responsible for a more rugged topography in a northeast trending belt through Middletown. Southeast of Middletown greywackes become thin and rare in a mudstone and shale unit. Whereas the recognition of a contrast between a greywacke poor to a greywacke lacking unit and a greywacke rich unit may be possible and meaningful even in this area of relatively poor outcrop, the finer distinction to the northwest is probably hard to demonstrate and Offield (1967) admits that it is difficult to define a boundary there.

Bedding, cleavage, axial planes and fold hinges strike or trend 040° to 050°, a significant deviation from the standard 020° to the north. Cleavage is often developed and dips almost always moderately to the east (Offield 1967).

The most obvious structure is a large scale north plunging fold, a western anticline followed by an eastern syncline. They are well defined by the curved contact between shale and underlying shelf carbonates. The core of the anticline exposes basement. The asymmetry of the anticline having a very gently west dipping western limb and a steeply dipping eastern limb could be the result of a blind basement backthrust terminating under the steep eastern limb. A blind backthrust provides some explanation for the asymmetry and is compatible with the west over east sense of a mapped, steeply dipping fault near the axis of the anticline. Additional mild later regional folding is likely and steepened structures.

Northeast and southwest of Middletown bedding dips consistently to the west. Occasional steep beds and one overturned bed are thought to indicate folding at a position where a blind thrust ramps up and terminates at depth similar as described above for Rt. 17 roadcuts. The general west dip and lack of horizontal beds above the inferred flats indicates steepening of dips by large scale folding.

A roadcut on Rt. 17 between Middletown and Goshen, south of Philipsburg and 4.5 northwest of the Goshen interchange shows tight fold and faults (see photograph *in* Offield 1967). Offield (1967) asserts that intense deformation can be traced to the northeast following approximately the Wallkill River. This is indicated on his map by vertical or east dipping beds. Perhaps the isolated occurrence of shelf carbonates in the northwest corner of this sheet is also related to this deformation zone.

Observations of siliceous black slate and bright highly foliated phyllitic slate at Rt. 17 outcrops near Chester and the topographic distinctiveness of the core of the syncline south of Chester lead to the suggestion of a major modification of Offields (1967) map. Whereas Offield (1967) includes the core of the syncline into his shaley flysch unit, I think the observed higher metamorphic grade in the visited outcrops, which is thought to be responsible for the more hilly topography and much higher outcrop frequency within the core of the syncline as compared to low areas north and northwest (underlain by the same material according to Offield), indicates a separate unit, probably a Taconic thrust slice.

All of the structural information above is related to the problem of the location of the trace of the main basal detachment responsible for emplacement of the Taconic Allochthon and flysch onto the Medial Ordovician carbonate shelf and flysch.

As a major melange zone such as the Eastern Exotic Melange is nowhere reported, only indirect evidence can be used to constrain the location of the trace. As argued above it is likely that the detachment reappears from under Siluro-Devonian cover in the eastern Ellenville or the western Newburgh quadrangle. Folding and thrusting at Wurtsboro at the Taconic unconformity may have the detachment as the basal decollement from autochthonous material. In this case the detachment would disappear under Siluro-Devonian cover north of Wurtsboro. A Taconic overturned fold and associated thrusts to the south near Otisville at the Taconic unconformity support this. This hypothesis would locate the detachment far west. A hypothesis which includes the reasonable easternmost location of the detachment is that the Ganaghote fault zone is the (later reactivated) detachment. Deformed flysch west of it is then just the result of minor tectonic movements at the end of transport. The two hypothesis are in fact similar the difference being the larger amount of transport assigned to western flysch in the first hypothesis. In this sense the hypotheses are endmembers and intermediate solutions possible.

An important constraint is that the basement and overlying carbonates of the anticline in the Goshen quadrangle are most likely autochthonous because a conformable sequence is reported (Offield 1967) and because the detachment does not cut through basement elsewhere along the Taconic allochthon. This means that the detachment must be located in the shale overlying the carbonates to the north and west of the folded carbonates. If the synclinal core is allochthonous Taconic material then it is located right above the detachment with little or no allochthonous flysch sandwiched between the faults. In this case the earlier thrusting which emplaced the Taconic material onto the flysch and later movement of flysch and other material above the main detachment would have been occurred on the practically the same fault plane in this area. Attached shelf carbonates and nearby isolated occurrences of shelf carbonate could be thrust slivers which were picked up during emplacement. Unfortunately Offield (1967) does not report the structural state of these carbonates as compared to the structural state of the nearby autochthonous shelf carbonates.

Even if the trace of the detachment disappeared under the Siluro-Devonian cover it would have to reappear further south and return to the north of the autochthonous core of the anticline. The more strongly deformed zone east of the greywacke rich terrane and the isolated occurrence of shelf carbonate as a carbonate sliver in the northeast corner of this sheet could be related to such a returning (folded) detachment. The folding is also consistent with the (required) swinging south of the detachment under the allochthonous synclinal core. The isolated occurrence of shelf carbonate could also be related to the trace of a detachment along the Ganaghote fault zone which strikes towards it.

Because the detachment is probably located above the shelf carbonates it must be cut by a 045° striking major normal fault (Offield 1967, Fisher et al. 1970) which down-dropped its eastern block to expose Devonian sediments for example at Schunemunk Mt. in the Schunemunk Quadrangle.

Just west of this normal fault there is in the Goshen quadrangle the largest of a series of isolated basement knobs to the northeast along this fault. Offield (1967) observes sharp thrust contacts against Ordovician shale dipping 40° to 50° southeast at their western boundary. The nature of their eastern boundary is less clear. Offield (1967) suggests a normal fault contact from observations in the Catskill Aqueduct tunnel south of Newburgh by Holzwasser (1926). Jaffe and Jaffe (1989) argue for a thrust contact as they view the basement knobs as erosional remnants of a basement nappe. Offield (1967) and Jaffe and Jaffe (1989) suggest a Taconic age for the thrusting.

Schunemunk

No material concerning the structure of the Ordovician flysch in this sheet could be found. Jaffe and Jaffe (1989) assess the northeast trending series of isolated basement knobs. The lack of a positive geomagnetic anomaly over the basement knobs indicates that they are thin (less than ca. 200m). The texture of the basement gneisses is consistently more deformed and cataclastic than that of Precambrian gneisses to the southeast. There are fault breccias at the base of some of the knobs at the contact with Ordovician shale which are more strongly folded near the gneisses. These properties are consistent with the basement knobs being outliers of a thrust nappe. Jaffe and Jaffe (1989) explain the perfect alignment as being the fold axis of a syncline in which the nappe was preserved and elsewhere eroded. However, the axis of the large scale syncline in Offield's map (1967) projects about a half a wavelength west of the basement knobs which rather suggests that the basement knobs are far removed from a synclinal axis or even could be close to a crest of an anticline.

Perhaps the basement knobs are very big blocks in a melange under a basal detachment of a basement thrust sheet from which they are derived. The alignment would then indicate a steep dip for the melange zone perhaps achieved by later folding.

Summary

A belt of deformed Ordovician flysch can be traced through the central Hudson Valley. It is bordered to the east by allochthonous Taconic sequence sediments and to the west by undeformed flysch. The Frontal Exotic Melange decorates the entire length of the contact between the deformed flysch belt and the Taconic Allochthon and seems to crosscut large scale slices within the belt of deformed flysch. The flysch slices are separated by melange zones and are internally imbricated typically on a decameter scale when a good exposure is seen (e.g. Catskill, approach to Rip van Winkle bridge).

There is a change in style of thrusting along strike. In the north, in my detailed map area, broad melange thrusts dominate. To the south, south of Ravena, in general only thin melanges and discrete thrusts are observed with the exception of the Taconic Frontal Melange in the Poughkeepsie area. As this change coincides with a change of bulk lithology from shale/siltstone-dominated to greywacke-dominated in the area from Ravena to Kingston, the different styles of thrusting are probably material-dependent responses to the same shortening event. The occurrence of thick bedded greywackes in the HGZ within melange supports this inference. However, the assignment of discrete thrusts to a certain shortening event is problematic because of overprinting of Taconic structures by Acadian or/and Alleghanian shortening. Whereas melange occurrences are generally believed to be Taconic in age, because they are not observed in the Devonian, it is hard to demonstrate the age for any given occurrence of a discrete thrust in flysch. Lineations showing transport directions can be helpful, as post-Taconic transport tends to trend 090° (Marshak and Tabor 1989) and Taconic transport 110-120°. The minor amount of offset by post-Taconic thrusts (Marshak 1986) suggests that not every discrete thrust is of post-Taconic age.

The Quassaic Group, distinct by its marine "molasse" sediments and its north-south orientation, has a sharp probably tectonic eastern contact with Medial Ordovician flysch and an unexposed western contact of unknown nature. A possibly Late Ordovician age and its distinct lithology are consistent with a piggy-back basin environment. The north-south orientation, oblique to the strike in structures in the surrounding flysch and projecting into the post-Taconic Hudson Valley Fold and Thrust belt, suggests a post-Taconic, tectonic definition of its contacts.

Tight folding, frequent thrusting and occasional melange zones east of the Wallkill River followed by a western decrease in deformation correlates well with the succession of structures in the Capital District in the north. Since in my detailed map area the basal detachment was recognized, separating allochthonous flysch from autochthonous flysch, and since units, thrusts and trends can generally be traced to the south, this basal detachment must reappear in the south at the latitude of Ellenville somewhere in a ca. 15km broad belt west of the Wallkill River. Approximately along the Wallkill River a previously identified major fault zone could be the basal detachment or an imbricate thrust joining it at depth. West of this belt at this latitude Taconic deformation is restricted to mild open folding. At the latitude of Middletown to the south, Taconic thrusting is observed close to the Taconic unconformity at a position much further west than the position of the proposed detachment to the north. This is consistent with the general change of the regional strike to 045° in this area which bends tectonic belts more to the west.

Late large scale folding south of Middletown exposes autochthonous basement and overlying shelf carbonates in the core of a gently north plunging anticline. The folded basal detachment cuts through overlying flysch and must therefore occur north of the exposed carbonates. Isolated shelf carbonates in this area are possibly fault slivers attached to the basal detachment or imbricate thrusts joining it. There are indications that the core of the corresponding syncline east of the anticline exposes a previously unidentified piece of Taconic allochthon.

The Hamburg Allochthon in Pennsylvania

Medial to Late Ordovician flysch can be traced from southeastern New York through New Jersey into Pennsylvania (Williams 1978, McBride 1962). In Pennsylvania, between Harrisburg and Hamburg, a body of rock is found, the Hamburg allochthon (klippe), which is anomalous with respect to the age and lithology of its surroundings (Lash and Drake 1984). The Hamburg allochthon is considered to be a Taconic allochthon, similar to the Taconic allochthon in New York, and can be divided into two slices (Lash and Drake 1984) The southeastern, upper Richmond slice contains Late Cambrian to Early Ordovician rocks deposited on a slope adjacent to carbonate shelf and structurally overlies the northwestern Greenwich slice. The Greenwich slice contains some Early to Medial Ordovician chert, deepwater limestone and variegated shale (Lash 1990) and Medial Ordovician shale and greywackes. The Greenwich slice is characterized by melange type deformation including phacoidal cleavage and block-in-matrix structures (Lash and Drake 1984). Judging from their description and some photographs this melange appears to be very similar to melange found in my detailed field area (not to mention the location of their main melange locality near a village called Albany). The Summerdale allochthon (Root and MacLachlan 1978) at the western end of the Hamburg allochthon is lithologically similar to the Greenwich slice and has characteristics of a highly sheared melange. The Greenwich slice is in thrust contact with underlying Medial to Late Ordovician fine grained flysch, the Shochary Ridge sequence (Lash 1990), which is in thrust contact with underlying flysch, the Martinsburg Formation. The Martinsburg in Pennsylvania seems to be cut only by minor thrusts (Lash and Drake 1984) because its three sedimentary members can still be recognized in long belts (Lyttle and Epstein 1987, map, Lash 1990).

Lash and Drake (1984) interpret the Greenwich slice as an accretionary complex above a basal detachment and produced in front of an advancing Taconic allochthon. The chert, deepwater limestone and variegated shale are found as "exotic" blocks in the melange and are interpreted as pelagic sediments which were included in the melange early in the accretion process. The Greenwich slice disappears to the northeast under overthrust Cambrian and Ordovician carbonates..

The similarity between the Greenwich slice and the melange-dominated eastern half of my field area in lithological, mesoscale structural, and larger-scale tectonic aspects indicates that there has been originally a long coherent detachment corresponding perhaps to an overall simple collisional setting.

Correlation with Champlain thrust

The deformation found in my detailed field area can not only be traced to the south but also to the north. Descriptions of thrusts between Saratoga Lake and the state border to Vermont west of the Taconic allochthon are found in Bosworth and Vollmer (1981) and Bosworth et al. (1988). Other workers in this area include Ruedemann (*in* Ruedemann and Cushing 1914), Steinhardt (1983) and Fisher (1984). I visited outcrops near Ballston Spa, around northern Saratoga Lake and between Saratoga Lake and Schuylerville.

Tracing of thrusts to the north is important as it links these faults with the Champlain thrust system (including Champlain, Orwell, St. George, Shoreham, Pinnacle, Highgate Springs, Philipsburg, Rosenberg and other thrusts) of Vermont, which is generally considered to be the basal detachment under the Taconic allochthon and eastern basement accommodating significant displacements (Rowley and Kidd 1981, Rowley 1983, Stanley and Ratcliffe 1985, Ando et al. 1983).

Correlation of thrusts west of the Taconic Frontal Thrust in New York and the Champlain Thrust system was suspected by previous workers (Rowley 1983, Stanley and Ratcliffe 1985), but not discussed in detail. I think one can show fairly well the continuity of the thrusts and accompanying deformation from the New York state border at the Poultney River into the Capital District.

Steinhardt (1983) mapped the area between the Taconic Frontal Thrust and autochthonous (?) Grenville basement and overlying shelf carbonates in the West Haven, Vt., area across the state border. His mapping could clearly identify three thrust sheets below the Taconic Allochthon. Steinhardt (1983) correlates the thrusts below these sheets with three thrusts identified 15 km north of his field area by Coney et al. (1972) which join into the Champlain thrust further north. To the south his thrusts project into subsequently mapped melange zones in flysch (Bosworth et al. 1988). Therefore Steinhardts mapping (1983) provides a major link between the Champlain Thrust system in Vermont and the melange zones in New York.

Bosworth et al. (1988) and Vollmer and Bosworth (1984) show a regional sketch map indicating melange zones between Steinhardt's field area and south of Albany. There are large gaps between the mapped melange occurrences in this map. My detailed mapping fills one of the larger gaps. Another large gap is between south of Hudson Falls and the Mettawee River. On their cautiously interpreted maps, melange zones are not convincingly continuous and could be interpreted as minor thrusts in essentially autochthonous flysch. I found that lithostructural belts are continuous in my detailed field area and correlate well with Vollmer's (1981) mapping south of Albany, and that part of the flysch is highly allochthonous. This suggests that the observed isolated melange zones to the north are exposed parts of a continuous thrust array or imbricate thrust system. This continuity is obvious, for example, for the Schuylerville area, for which Vollmer and Bosworth (1984) present a more detailed map. East of the continuation of the Folded Thick Greywacke in the Rocky Tucks (Cushing and Ruedemann 1914, and my own reconnaissance mapping) they identify the continuation of the Eastern Exotic Melange which contains there, just north of Schuylerville at Stark's Knob, a pillow basalt block. East of the Eastern Exotic Melange there is strongly deformed flysch with thin melange zones, but no exotic lithologies. This belt appears to be another flysch slice equivalent to those recognized further south. A difference to similar flysch in my area is that in the Schuylerville area, shale often has slaty cleavage. The Taconic Frontal Thrust is bordered by an equivalent of the Frontal Exotic Melange which is capped, near Bald Mt., with large fault slivers of shelf carbonate directly below the Taconic allochthon.

It is also possible to trace the western limit of deformation, also known as Ruedemann's line, farther north. It turns out that it approximately parallels the strike of the Taconic Frontal Thrust and of the melange zones west of it. Therefore Ruedemann's line is probably related to this deformation and its continuity to the north provides another link.

My mapping indicated, in agreement with Ruedemann (1930) and Cushing and Ruedemann (1914), that this line follows, at the northern limit of my detailed map area, the course of the Mourning Kill just east of Ballston Spa. At Saratoga Springs medial Ordovician shelf carbonates and overlying shale are undeformed. Cushing and Ruedemann (1914) draw Ruedemann's line from east of Saratoga Springs to the vicinity of Gansevoort through an area of very limited exposure north of Saratoga Lake. North of Gansevoort, Bosworth (1984) reports cleaved, folded and faulted shale in the northern branch of Snook Kill. This occurrence projects Ruedemann's line into the vicinity of Hudson Falls. Fisher (1984) reports moderate to steep east dips in shaley flysch 3.5km east of the Hudson River and Hudson Falls, just west of the Old Champlain Canal north of Dunham Basin. Underlying shelf carbonates to the west have gentle dips. To the north it is possible that the fault which is represented by Ruedemann's line cuts down section into Ordovician and Cambrian shelf carbonates in the Fort Ann area and into underlying basement further north following a valley which leads to the southern end of Lake Champlain, South Bay.

If this is the case then the Welch Hollow fault of Fisher (1984) which juxtaposes eastern basement with western Cambrian and Ordovician carbonates and shale could be a basement thrust which joins the thrust represented by Ruedemann's line further north. The conformable carbonate sequence which overlies this possible basement slice to the east dips fairly constantly 10° +/- 2° to the east which would be a plausible dip for the possible basement thrust. By applying an east dip of 10° and measuring horizontal distances on Fisher's map (1984), a thickness of 2.8 km for the sedimentary cover from the unconformity to the sharp carbonate-flysch contact and a maximum thickness of basement of 5.1 km measured downwards from the unconformity to the thrust is calculated. Alternatively it is possible that the belt of deformed rocks west of the Taconic Frontal Thrust narrows considerably north of Hudson Falls and Ruedemann's line joins into a melange zone in flysch above the conformable section of shelf carbonates above autochthonous basement.

Line 1 of the COCORP New England Appalachian traverse extends eastwards from near Glens Falls to Windsor, Vt. (Ando et al. 1983). At 1.5s two-way travel-time it recorded a series of subhorizontal events, which turn downward near the east flank of the Green Mountains (on line 3). Some not very well-defined eastward dipping reflectors climb westward and project west of the Taconic Frontal Thrust. At an average seismic velocity of 6 km/s the subhorizontal reflectors probably lie under the entire thickness of the Taconic allochthon with possibly a 2 or 3 km thick layer between the reflectors and the base of the allochthon (Ando et al. 1983). These reflectors are commonly interpreted to be the basal detachment under the Taconic allochthon (Ando et al. 1983, Stanley and Ratcliffe 1985, Stanley 1987) controlled by layering in the shelf carbonates or overlying flysch. However, the lithologic contrast between basement and cover or between platform carbonates and overlying shale provides perhaps a more plausible physical counterpart to the seismic events concerend since either contact likely occurs in the depth range suggested by the travel-time. If one follows, on the contrary, the common interpretation, then the basal detachment is inferred to be in the same structural position as the Champlain thrust system and may break the surface between the Taconic Frontal Thrust and Glens Falls. This is another indication of the continuity of the Champlain Thrust system to the south into my field area. If one correlates the horizontal reflectors with the contact between undeformed sediments and deformed sediments and assumes a total width of 15km between the base of Taconic allochthon, the Taconic Frontal Thrust, and Ruedemann's line and assumes a vertical thickness of 2 to 3 km for the same deformed belt under the Taconic allochthon, one arrives by simple trigonometry at a dip near the surface for the basal detachment of 7.6° to 11.3°. This argument therefore supports gentle dips for the shear zone boundaries for all areas where there is a broad belt of deformed flysch west of the Taconic Frontal thrust.

Results of the compilation and tectonic interpretation

An integrative overview of deformed medial Ordovician flysch in New York state shows that there is a continuous, 10 to 20km broad belt of strongly deformed flysch west of the Taconic Frontal Thrust. This belt has several characteristics:

- occurrences of systematic assemblages of older non-flysch lithologies

- occurrence of extensive melange zones
- alternation of melange zones and bedded slices
- small scale imbrication
- continuity of the Frontal Exotic melange
- kinematic equivalence to the Champlain Thrust system

The good continuity of this belt and its kinematic equivalence to the Champlain Thrust system reinforce the proposal of the belt representing the main basal detachment responsible for emplacement of the assembled Taconic allochthon, which was based on the occurrence of highly sheared and extensive melange zones and highly allochthonous assemblages of non-flysch lithologies in my detailed field area.

The Frontal Exotic melange under the Taconic frontal thrust is the most easily identified and most continuous belt within the belt of deformed flysch. This and indications that the Frontal Exotic melange/Taconic Frontal thrust crosscuts flysch slices suggests that the Taconic Frontal thrust is a late feature relative to structures in the deformed flysch and that it brought up and helped form the Frontal Exotic melange. This relative younger age with respect to deformation in the deformed foreland argues against the suggestion of Bosworth et al. (1988) that most melanges in the deformed flysch are related to the Taconic Frontal thrust, but is consistent with the crosscutting, unfolded nature of Taconic Frontal Thrust (Bosworth et al. 1988).

As a result of the compilation two thrust systems are now more clearly identified in the deformed foreland west of the Taconic allochthon, an early thrust system and the later Taconic Frontal thrust system. The early thrust system was responsible for the main emplacement of the Taconic allochthon and is probably the major contributor to the formation of major melange zones. The Taconic Frontal thrust system imbricated the emplaced Taconic allochthon and flysch terrane and probably also helped forming the melange as suggested by the close relation of Frontal Exotic melange and Taconic Frontal thrust.

CONCLUSIONS

Investigation of the 15-20km wide medial Ordovician deformed foreland west of the Taconic boundary thrust on an outcrop scale (10m), local map scale (10km) and regional scale (100km) leads to the following conclusions:

1) Although glacial cover restricts observations severely, a combination of outcrop scale information and map pattern information on a scale which allows sensible grouping of outcrops can still provide the foundation for relevant results.

2) Between Albany and Saratoga Lake the deformed foreland can be divided broadly into two belts with a fairly abrupt boundary between them, a western belt of folded and faulted flysch and an eastern melange-dominated belt. Since the melange is tectonically derived and in parts highly allochthonous, the boundary between these belts is the surface trace of the basal detachment under the Taconic allochthon following a line between Saratoga Lake and (under) the uptown campus of the University at Albany. This detachment is responsible for most of the emplacement of the Taconic allochthon and did not build out much into flysch stratigraphically overlying shelf carbonates to accrete additional major flysch slices. Only towards the end of emplacement was flysch in front of the detachment deformed and the resulting melange imbricated.

3) Compilation of available data suggest that the belt of deformed foreland is continuous from the New York - Vermont State border to Middletown in southeastern New York State. It can be linked to the Champlain thrust system of Vermont. The basal detachment disappears south of Albany under Devonian cover and reappears from under Siluro-Devonian cover at the latitude of Ellenville west of the Wallkill River where a

succession of western less-deformed flysch to eastern complexly deformed flysch, including melanges, can be correlated with similar belts along the Mohawk River (Epstein and Lyttle 1987). South of Ellenville in the Port Jervis and Goshen 15'-quadrangles the trace of the basal detachment is less clear. Previous investigations of post-Taconic deformation south of Catskill (Marshak 1986, Tabor and Marshak 1989, Lyttle and Epstein 1987) suggest a minor role for it compared to Taconic deformation.

4) The Taconic Frontal Thrust and the associated Exotic Frontal Melange are the most continuous features in the compiled area. The relatively undisturbed character suggests a late origin for these features. This late age is supported by slices and thrusts in the melange belt which trend obliquely to, and are crosscut by, the Taconic Frontal Thrust/ Exotic Frontal Melange.

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APPENDIX 1

POINT COUNTING RESULTS FROM 7 GREYWACKE THIN SECTIONS

In order to substantiate the qualitative distinction in outcrop and thin section between greywackes from flysch melange and "exotic" greywackes from melange bearing non-flysch assemblages, the composition of the greywackes was quantitatively analyzed by point counting of seven thin sections (a,b,c,d,e,f,g) from the seven greywacke samples (0911-2a, 0911-2b, 0911-2c, 0911-2d, 0911-2e, 0911-2f). An extensive point counting study of 237 thin sections of medial Ordovician Hudson Valley flysch was made by Tanski (1984). He attempted to characterize the Pawlet, Austin Glen, Schenectady/Frankfort and Quassaic Formations. Since the goal of my point counting analysis was just to test the distinctiveness of the two groups of greywackes, no direct comparison with Tanski's data was made.

Methods

After an overview of the thin sections and test point counting, ten categories were established, which promised to be sufficiently abundant in single thin sections and comparable between the thin sections. Tools used were a Swift automatic counter (Model F) and a binocular Olympus BHT System microscope. Grid point distance was chosen such that one grain was never counted twice and was at least two times the size of larger grains. 500 to 556 points were counted per thin section. After every 30 to 70 points preliminary results were noted during the counting procedure.

The reliability of the results for individual sections was examined by plotting percentages of categories at several stages of one counting procedure against the number of counted points (figs. A1-7 to A1-13). If the percentage stabilizes towards higher numbers of counted points and approaches a horizontal line, then a representative and sufficient number of points was counted. If there is an upward or downward trend in the percentage, one has to expect further changes at higher amounts of counted points. 500 or more counted points prove in general to be sufficient. Somewhat unsatisfactory results are those for clay minerals and shale clasts in a, quartz/kspar in b, clay minerals in e, chert/poly-qtz in f and matrix/cement and shale clasts in g. However, all of those still include an useful level of information and were therefore not discarded for data analysis in a compromise between scientific rigor and a more pragmatic approach. For the better stabilized counts one may estimate an uncertainty by determining the deviations from the average horizontal line in the horizontal part of the plot.

Description of the counted categories

Three matrix/cement related categories (carbonate matrix/cement, residual opaques, clay minerals) and six clast categories (quartz/kspar, carbonate, shale, chert/poly-quartz, albite-twinned plagioclase, other lithics/heavy minerals) were counted. For two samples (f, g) matrix/cement was not subdivided and counted as one category. In one sample (b) shale clasts and residual opaques were only subdivided after 185 points were counted for which they were lumped together. No systematic attempt was made to recognize alkali feldspars. Occasional occurrences of microcline cross twinning and Carlsbad twinning, and biaxial conoscopic figures of large grains make it clear that a non-trivial percentage in the quartz/kspar category is alkali feldspar. Plagioclase was counted separately when it showed albite twinning. The probably small fraction of untwinned plagioclase was not identified and lumped with the quartz/kspar category. Since there is a transition between coarse grained, possibly recrystallized chert and polycrystalline quartz grains with a large number of subgrains, both were counted as one category. Possible fine grained quartz sandstone was also included here. A fairly high number of subgrains (>10 or so) was required for quartz to be included in this category, otherwise it was counted as quartz/kspar. Carbonate clasts are mostly biogenic. Shale clasts were identified when they show a dirty mixture of dark-brown or opaque matter, clay minerals and/or small quartz grains. Many showed signs of little or no lithification - wrapping around clasts; transitions into matrix; squashing on incorporation in the turbidite; and are thought to be rip up clasts. In some cases it was difficult to recognize shale clasts as clasts as opposed to matrix. The relatively low abundance of shale clasts and the highest abundances in residual opaques and clay minerals in a section which was counted first suggest that some shale clasts were not recognized as such. If clasts could not be assigned to any of those categories, they were counted as other lithics. Such clasts included non foliated and foliated, fine grained micaceous rocks without opaque matter, similar clasts with small quartz inclusions and one example of possible quartz-mica schist. In one section (e) two grains of heavy minerals (zircon and tourmaline) were counted and added to the other lithics category. No volcanics were found.

All samples show a fairly high amount of calcite in the matrix and as cement or overgrowth as compared to abundances of the other constituents and authigenic or entirely secondary clay minerals.

Data analysis

Fig. A1-1 shows the modes of the counted categories in tabulated form and figs. A1-2 and A1-3 in graphic form. In order to discriminate between "normal" greywackes (0911-2a,0911-2b,0911-2c) and "exotic" greywackes (0911-2d, 0911-2e, 0911-2f, 0911-2g) one may start by just looking at the modal abundances and testing if a suggested grouping is consistent with their assignment. Since probably always some parameters (as ratios) can be found which allow consistent grouping it is necessary to check how meaningful such groupings are, e.g. if some reasonable physical meaning can be assigned to such parameters. One may also reverse this thought and start an attempt to discriminate by suggesting plots with some genetic meaning.

Fig. A1-3 shows that there are no drastic differences in the modal abundances between "normal" and "exotic" greywackes. For every category there is always at least one sample of one group which has similar modal abundances to a sample from the other group. On the other hand for some categories a boundary abundance can be defined which separates the two groups. This is the case for shale clasts, chert/poly-qtz, twinned plagioclase and other lithologies/heavy minerals. No such claim can be made for the quartz/kspar, carbonate clast and matrix/cement categories. In the case of the low abundance category other lithics/heavy minerals this result was expected and the point counting added just the certainty of a more complete survey, the numbers being less

TABLE

of modal abundances of 10 point counting categories from seven greywacke samples

	0911-2a	0911-2b	0911-2c	0911-2d	0911-2e	0911-2f	0911-2g
qtz/ksp	0.348	0.386	0.530	0.583	0.447	0.390	0.484
carb.cl.	0.026	0.090	0.032	0.036	0.029	0.010	0.022
shale cl.	0.112	0.152	0.100	0.093	0.098	0.069	0.087
cht/plqz	0.030	0.012	0.032	0.038	0.053	0.092	0.048
tw.plag.	0.020	0.024	0.022	0.014	0.008	0.010	0.008
o.lit./hm	0.000	0.000	0.000	0.004	0.024	0.020	0.002
carb.mt	0.172	0.272	0.184	0.219	0.131	n.a.	n.a.
res.op.	0.118	0.040	0.044	0.004	0.037	n.a.	n.a.
clay	0.174	0.024	0.056	0.009	0.173	n.a.	n.a.
tot.mtrx	0.464	0.336	0.284	0.232	0.341	0.409	0.349
tot.pts	500	500	500	556	510	508	502

Figure A1-1 The table lists the modal abundances of ten counting categories derived from point counting of thin sections of seven greywacke sampled at the Rt.7 road cut. The counting categories are abbreviated as: qtz/kspr = quartz/kspar, carb.cl. = carbonate clasts, shale cl. = shale clasts, cht/plqz = chert / poly-quartz, tw.plag. = twinned plagioclase, o.lit./hm = other lithics/heavy minerals, carb.mt = carbonate matrix/cement, res.op. = residual opaques, clay = clay minerals, tot.mtrx = total matrix/cement, tot.pts = total number of points counted. For a more detailed description of those categories see text.

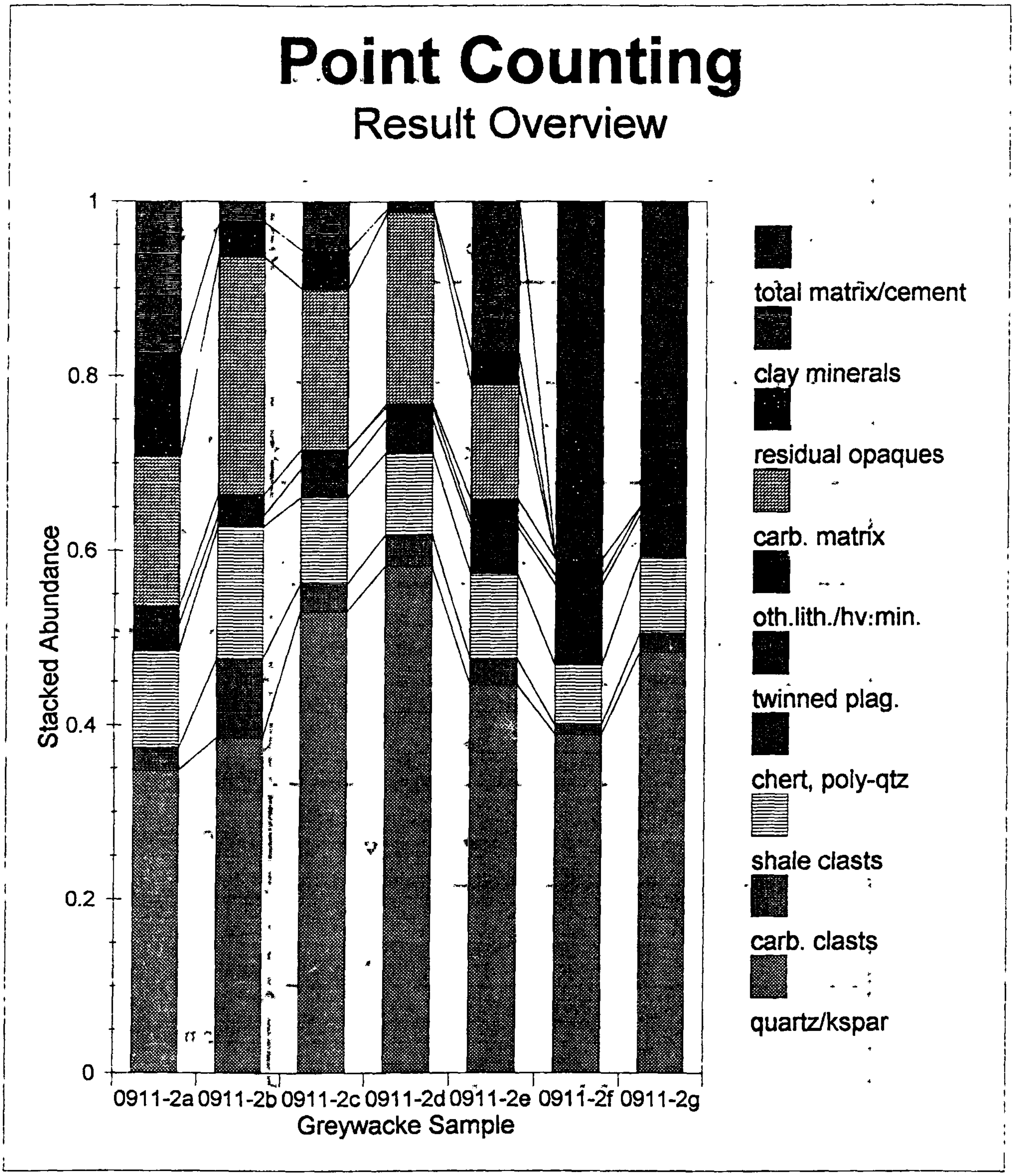

Figure A1-2 The stacked bar representation of the point counting results, the modes of the counting categories, gives a good and compact overview and allows for quick comparison of abundances between categories.

Result Summary

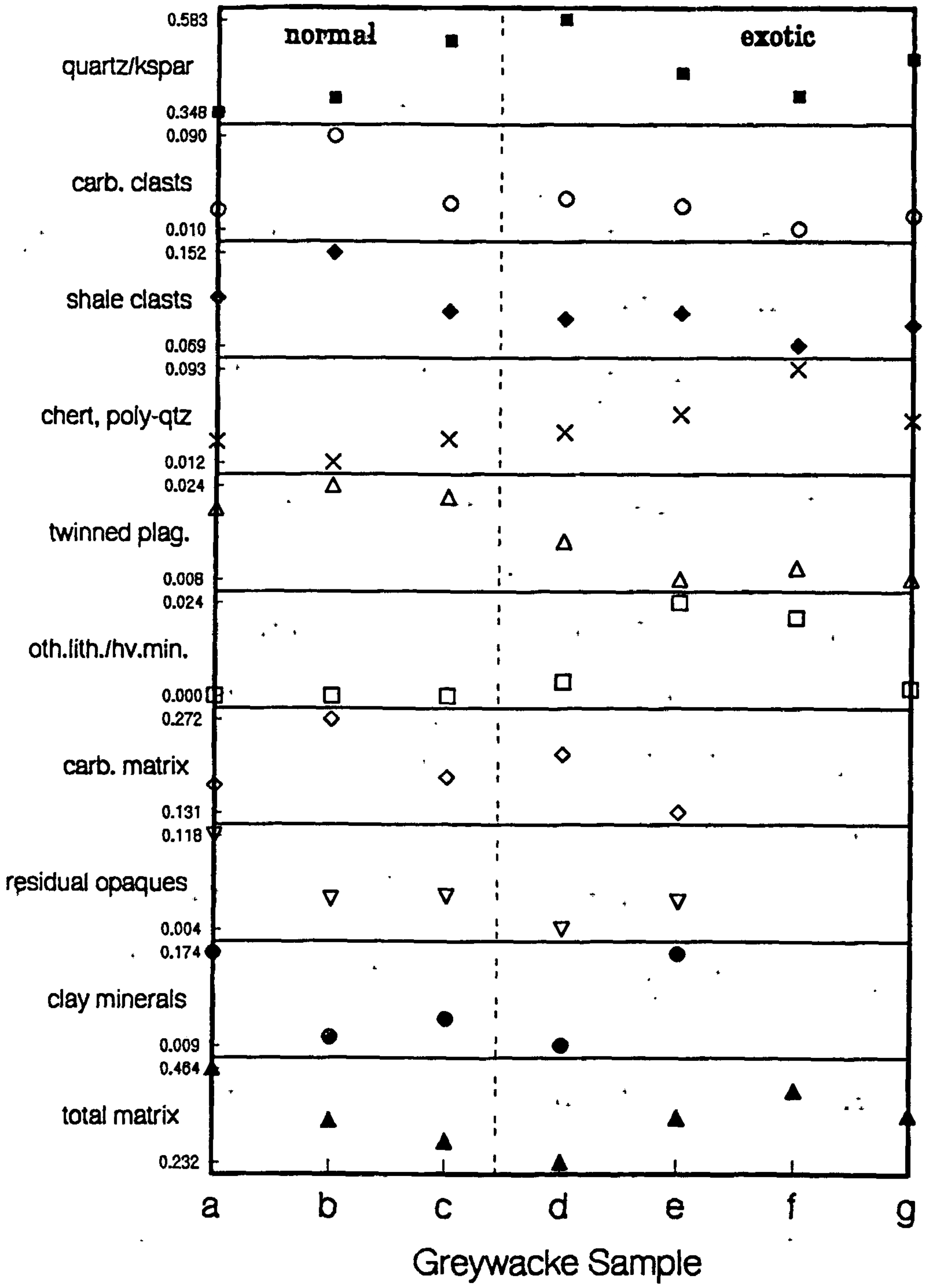

Figure A1-3 In this plot every category has its own scale, so that modes can be compared between the seven samples. The dashed vertical line separates "normal" from "exotic" samples.

important since in the "normal" sections no such clasts could be counted. Regarding the other low abundance category, twinned plagioclase, its separability in terms of modal abundances was not expected, but is clearly demonstrated. Both of those low abundance categories are not utilized in other discrimination plots because their relative uncertainty is considered too high to be useful in fractional parameters. In summary, the parameter modal abundance, which has the very direct physical meaning of representing a volume fraction of the rock, is discriminatory for some clast categories, but not for the major categories quartz/kspar and total matrix/cement. This supports the previously made suggestion that there is a distinct difference between two groups of overall similar rocks (greywackes).

Since only the clast population is thought to reflect potential differences in the composition of the source area(s), the data were normalized to 100% total clasts in order to subtract the effects of dilution by matrix/cement. This rationale does not take into account that also clast ratios are not only a function of the composition of the source area(s), but also a function of kind of transport and sedimentation like the matrix. Additionally unstable clasts may have been converted to matrix, although no phantom grain shapes were seen.

The summary plot of the normalized data (fig. A1-4) shows essentially the same relations as the plot of the modal abundance data despite the quite strongly varying (between 23% and 46%) amount of total matrix/cement. The separation of the shale in two groups clasts becomes slightly worse, chert-poly/qtz is similar and the separation for twinned plagioclase and other lithics/heavy minerals is slightly increased. The plot of the normalized shale data vs. the normalized chert/poly-qtz. data (fig. A1-5) can be separated

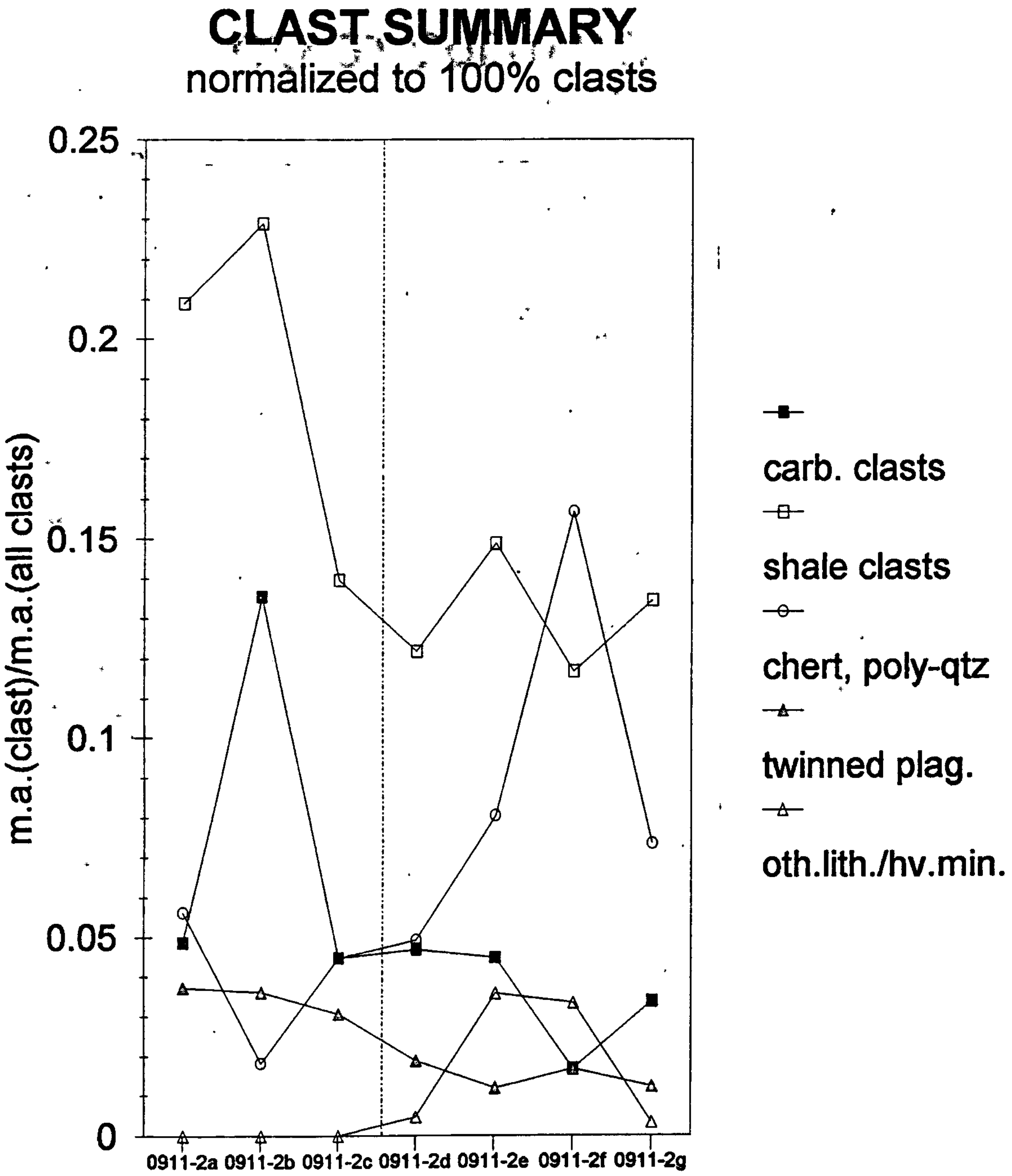

Figure A1-4 In this summary plot the influence of the diluting matrix was removed by normalizing clast abundances to the cumulative abundance of all clasts in a sample. The stippled vertical line separates between "normal" (left) and "exotic" (right) samples.

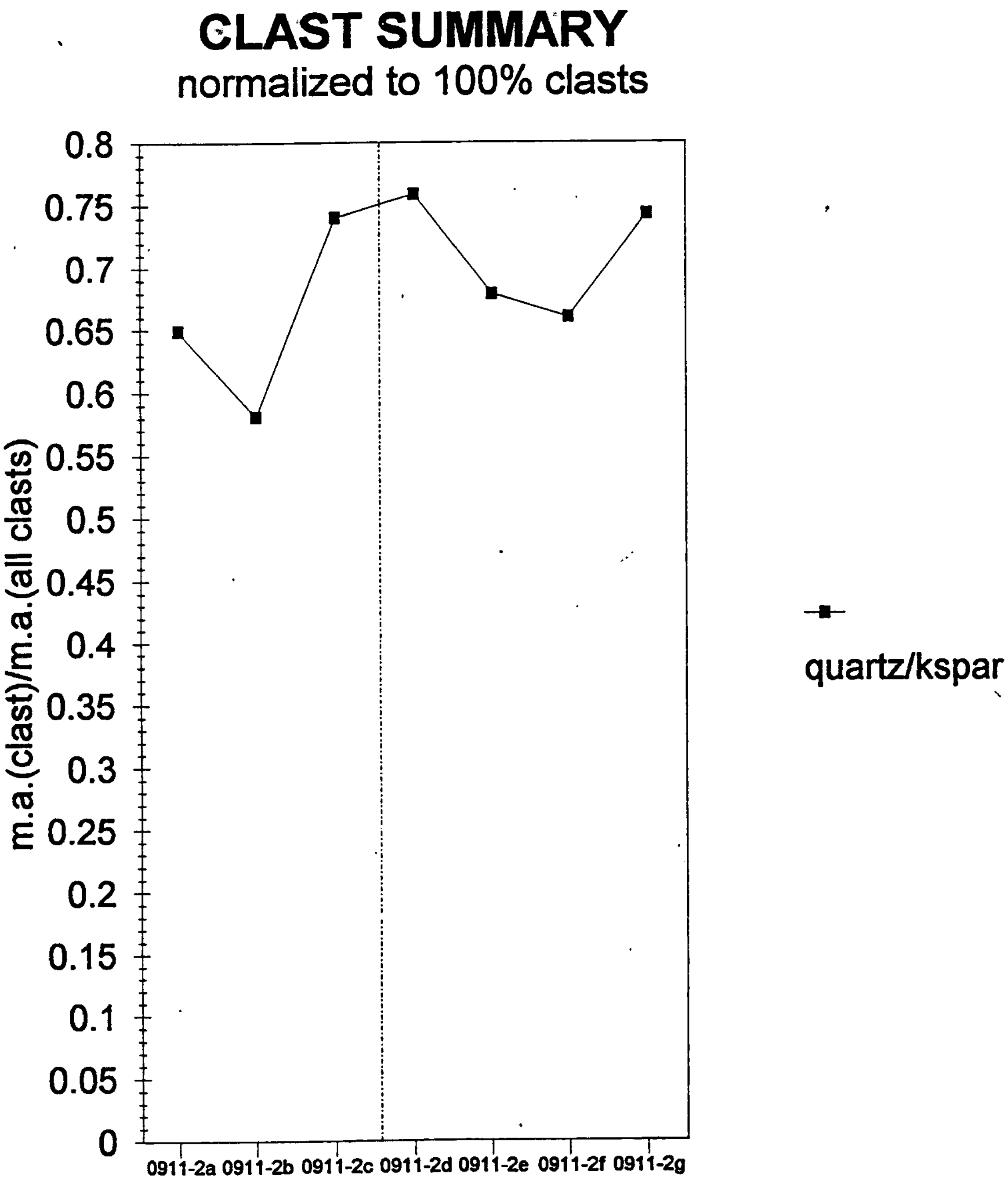

Figure A1-4 (continued) Quartz/kspar was separated from the other clast categories because it requires a different scale.

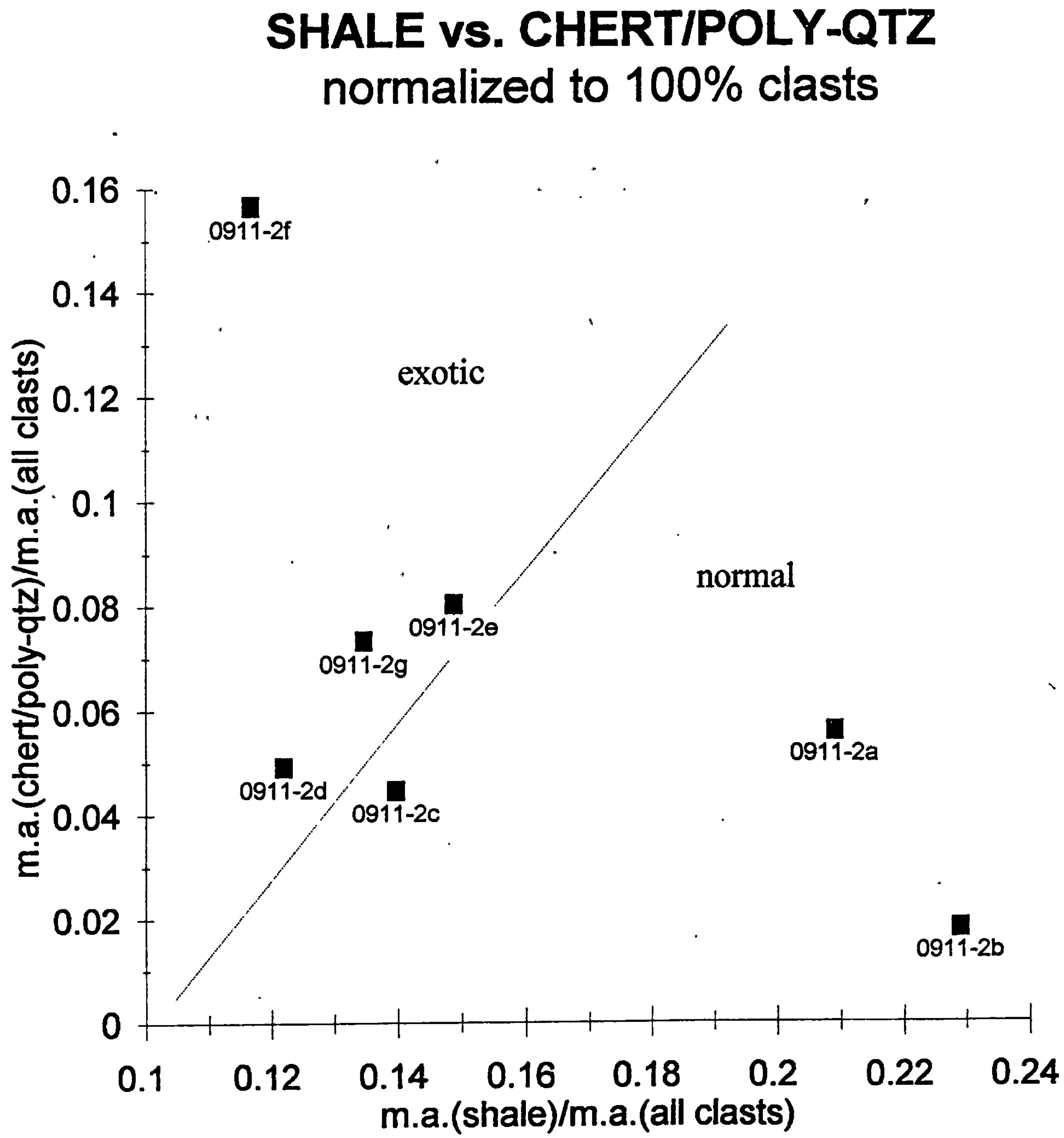

Figure A1-5 In the plot of the normalized abundances of shale clasts versus chert/poly-qtz a ratio separating between "normal" and "exotic" samples can be found. m.a.=modal abundance

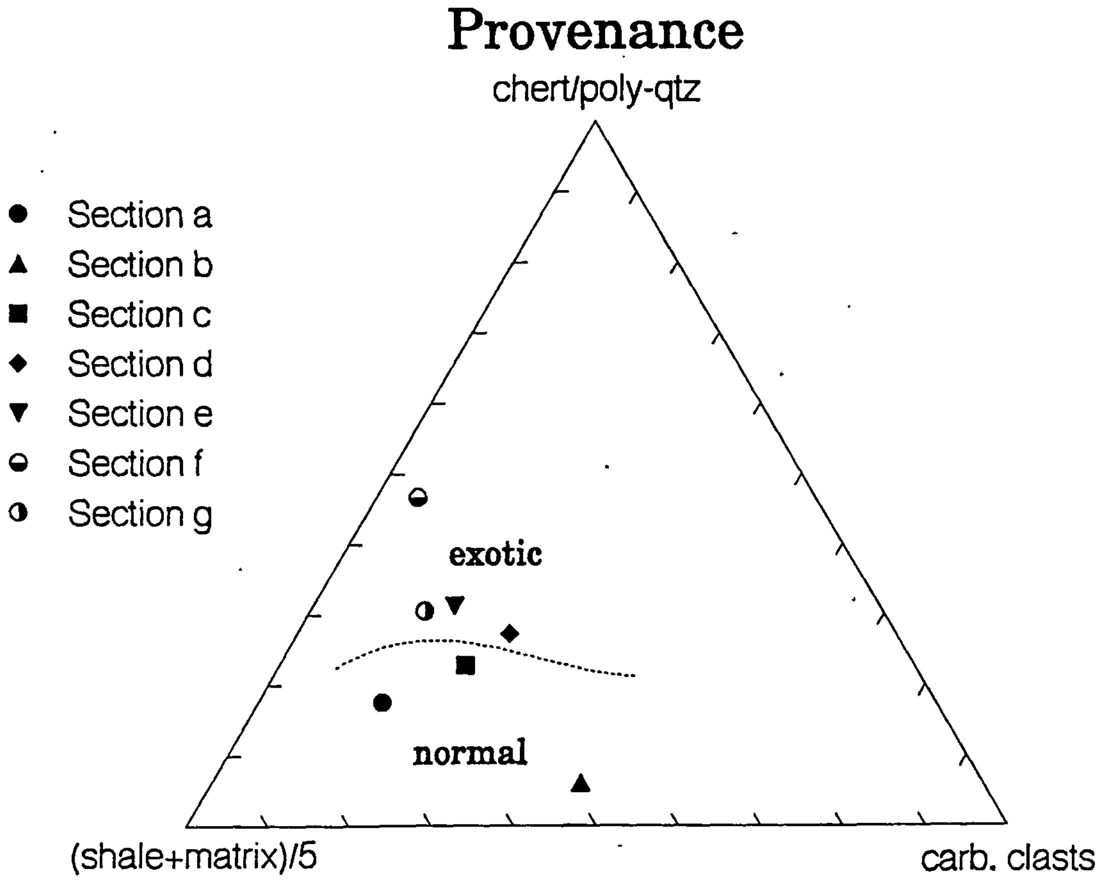

Figure A1-6 In this ternary plot, shale clasts and total matrix/cement abundances characterize the depositional environment, whereas carbonate clast and chert/poly-qtz clast abundances characterize provenance. "Normal" and "exotic" greywackes occupy two different regions.

in two halves by a critical ratio.

The shale clast abundance and the total matrix/cement abundance are the categories which are most influenced by the kind of transport and deposition of the greywackes and the carbonate clast and the chert/poly-qtz categories are thought to characterize best the source area. A ternary plot of chert/poly-qtz, carbonate clast and the sum of shale clasts and total matrix/cement abundances (fig. A1-6) was thought to reflect differences in provenance and depositional environment and to be potentially discriminating. A factor was included in the parameter for the depositional environment in order to push data points more to the center of the plot. Again, no clustering of the two groups is discernable, but they occupy easily separable regions in the plot.

POINT COUNTING DATA OF 7 GREYWACKE THIN SECTIONS

Notes on the tables

The tables show the counting evolution of each sample. For each section preliminary results were recorded after each 30-70 counts. The final count is, of course, the basis for the modal abundances used in the data analysis. All results were checked for consistency with the help of a spreadsheet program by adding counts of all count categories and comparing the sum with the recorded total number of counted points for equivalency. In sample 0911-2b the values for residual opaques and shale clasts up to a total count of 185 are just fractions of their sum proportional to their final ratio 12/47 since only their sum was recorded up to this number of total counts. The category other lithics/heavy mineral was not encountered in the samples 0911-2a, 0911-2b and 0911-2c and is therefore omitted. The category matrix/cement is just the sum of the categories carbonate matrix/cement, residual opaques and clay minerals, except for samples 0911-2f and 0911-2g. In these samples the matrix/cement was not subdivided and counted as bulk matrix/cement. Each table has a plot which allows some judgement of the reliability and, in some cases, the associated uncertainty in the sense of repeated measurements.

TABLE I

Sample 0911-2a

Ct.Pts.	qk	cc	cmc	ro	cm	sc	cp	tp	tmc
77	32	3	15	13	7	0	5	2	35
153	54	3	24	20	32	11	6	3	76
236	82	6	39	30	47	17	9	6	116
318	116	6	58	37	60	25	10	6	155
398	141	9	66	48	72	43	12	7	186
477	167	13	82	54	81	55	15	10	217
500	174	13	86	59	87	56	15	10	232

TABLE II

Sample 0911-2b

Ct.Pts	qk	cc	cmc	ro	cm	sc	ro+sc	cp	tp	tmc
52	19	8	13	*2*	0	*8*	10	0	2	*15*
110	39	11	27	*5*	4	*20*	25	1	3	*36*
160	57	14	44	*6*	7	*25*	31	2	5	*57*
185	66	15	48	*8*	9	*29*	37	4	6	*65*
235	83	21	63	11	10	35	*46*	4	8	*84*
284	102	25	78	13	10	42	*55*	4	10	*101*
340	122	29	95	15	11	53	*68*	5	10	*121*
391	146	36	108	15	11	59	*74*	5	11	*134*
441	169	40	119	18	12	67	*83*	6	12	*147*
500	193	45	136	20	12	76	*96*	6	12	*168*

qk=quartz/kspar,cc=carbonate clasts,cmc=carbonate matrix/cement, ro=residual opaques, cm=clay minerals, sc=shale clasts, cp=chert/poly-qtz, tp=twinned plagioclase, tmc=total matrix/cement, Ct.Pts.= counted points

TABLE III

Sample 0911-2c

Ct. Pts.	qk	cc	cmc	ro	cm	sc	cp	tp	tmc
77	41	3	15	3	5	6	2	2	*23*
158	85	3	33	8	11	8	6	4	*52*
190	105	3	38	9	13	12	6	4	*60*
222	122	3	41	10	15	16	10	5	*66*
263	139	6	50	12	16	22	11	7	*78*
302	158	7	57	13	18	28	14	7	*88*
343	182	9	61	16	21	32	14	8	*98*
396	210	13	68	18	26	37	15	9	*112*
445	238	13	81	21	26	43	15	10	*128*
500	265	16	92	22	28	50	16	11	*142*

TABLE IV

Sample 0911-2d

Ct.Pts	qk	cc	cmc	ro	cm	sc	cp	tp	tmc	ol
55	29	3	13	0	2	4	2	2	*15*	0
111	55	8	27	0	3	10	5	2	*30*	1
168	82	9	42	0	5	15	11	3	*47*	1
223	117	12	49	1	5	21	12	5	*55*	1
288	157	14	58	1	5	33	14	5	*64*	1
346	194	17	73	1	5	34	15	6	*79*	1
419	238	17	91	1	5	40	17	8	*97*	2
485	284	17	103	1	5	48	17	8	*109*	2
558	324	20	122	2	5	52	21	8	*129*	2

qk=quartz/kspar,cc=carbonate clasts,cmc=carbonate matrix/cement, ro=residual opaques, cm=clay minerals, sc=shale clasts, cp=chert/poly-qtz, tp=twinned plagioclase, tmc=total matrix/cement, ol=other lithics/heavy minerals,Ct.Pts=counted points

TABLE V
Sample 0911-2e

Ct.Pts	qk	cc	cmc	ro	cm	sc	cp	tp	tmc	ol
37	14	3	3	0	9	6	1	0	*12*	1
74	25	4	9	5	14	11	3	0	*28*	3
111	43	4	13	8	20	13	6	0	*41*	4
148	62	6	18	9	22	16	9	2	*49*	4
186	78	8	29	10	25	19	10	2	*64*	5
226	98	8	33	13	28	22	12	3	*74*	9
265	116	11	36	15	35	27	13	3	*86*	9
306	135	12	41	16	42	30	16	3	*99*	11
349	153	12	41	16	55	33	20	3	*112*	11
390	171	12	54	17	64	35	23	3	*135*	11
429	189	15	57	19	70	40	23	4	*146*	12
470	209	15	61	19	81	45	24	4	*161*	12
510	228	15	67	19	88	50	27	4	*174*	12

TABLE VI
Sample 0911-2f

Ct.Pts	qk	cc	cmc	ro	cm	sc	cp	tp	tmc	ol
49	18	0	n.a.	n.a.	n.a.	5	7	0	18	1
84	30	3	n.a.	n.a.	n.a.	5	13	0	30	3
122	44	3	n.a.	n.a.	n.a.	6	16	1	47	5
160	60	3	n.a.	n.a.	n.a.	11	20	1	59	6
199	72	3	n.a.	n.a.	n.a.	18	23	2	75	6
238	88	4	n.a.	n.a.	n.a.	19	27	2	91	7
274	100	4	n.a.	n.a.	n.a.	20	30	2	111	7
312	117	4	n.a.	n.a.	n.a.	23	34	2	125	7
352	136	4	n.a.	n.a.	n.a.	25	37	2	139	9
391	149	4	n.a.	n.a.	n.a.	29	40	3	157	9
429	160	4	n.a.	n.a.	n.a.	30	42	4	179	9
469	182	4	n.a.	n.a.	n.a.	33	44	4	193	9
508	198	5	n.a.	n.a.	n.a.	35	47	5	208	10

TABLE VII

Sample 0911-2g

Ct.Pts	qk	cc	cmc	ro	cm	sc	cp	tp	tmc	ol
29	15	1	n.a.	n.a.	n.a.	1	2	2	9	0
57	28	1	n.a.	n.a.	n.a.	5	3	2	17	1
89	46	2	n.a.	n.a.	n.a.	9	5	3	23	1
121	61	4	n.a.	n.a.	n.a.	14	7	3	31	1
154	78	5	n.a.	n.a.	n.a.	18	7	3	42	1
189	95	5	n.a.	n.a.	n.a.	23	11	3	51	1
224	109	5	n.a.	n.a.	n.a.	25	12	3	69	1
261	130	5	n.a.	n.a.	n.a.	28	14	3	80	1
297	149	5	n.a.	n.a.	n.a.	30	16	3	93	1
333	172	6	n.a.	n.a.	n.a.	33	17	3	101	1
372	190	7	n.a.	n.a.	n.a.	36	18	4	116	1
408	202	7	n.a.	n.a.	n.a.	38	20	4	136	1
441	218	8	n.a.	n.a.	n.a.	41	20	4	149	1
472	232	9	n.a.	n.a.	n.a.	43	22	4	161	1
502	243	11	n.a.	n.a.	n.a.	44	24	4	175	1

qk=quartz/kspar,cc=carbonate clasts,cmc=carbonate matrix/cement, ro=residual opaques, cm=clay minerals, sc=shale clasts, cp=chert/poly-qtz, tp=twinned plagioclase, tmc=total matrix/cement, ol=other lithics/heavy minerals

Numbers in italics in tables indicate that they are calculated from other data.

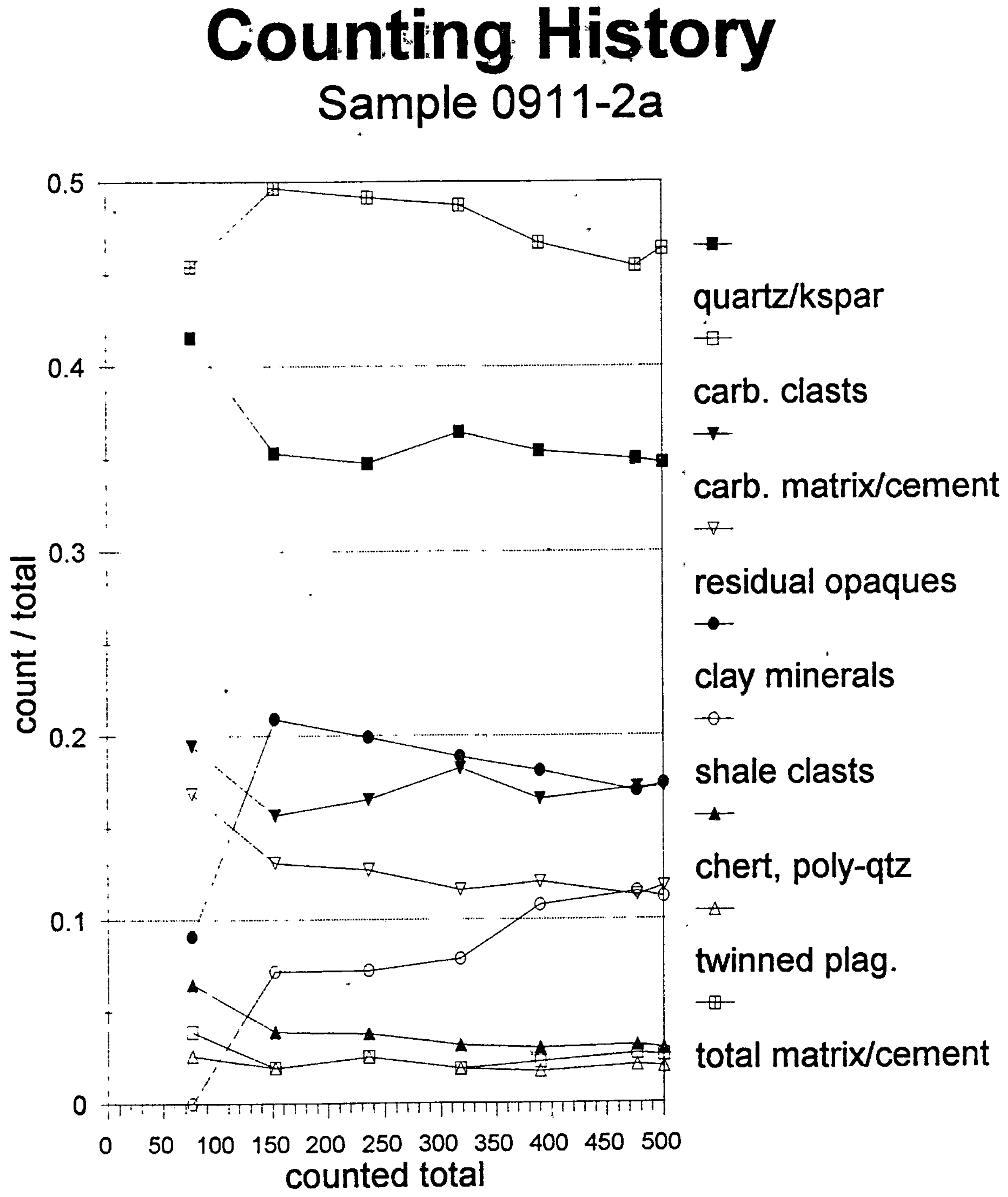

Figure A1-7 History plot of point counting data of sample 0911-2a indicating how final value for abundance stabilizes.

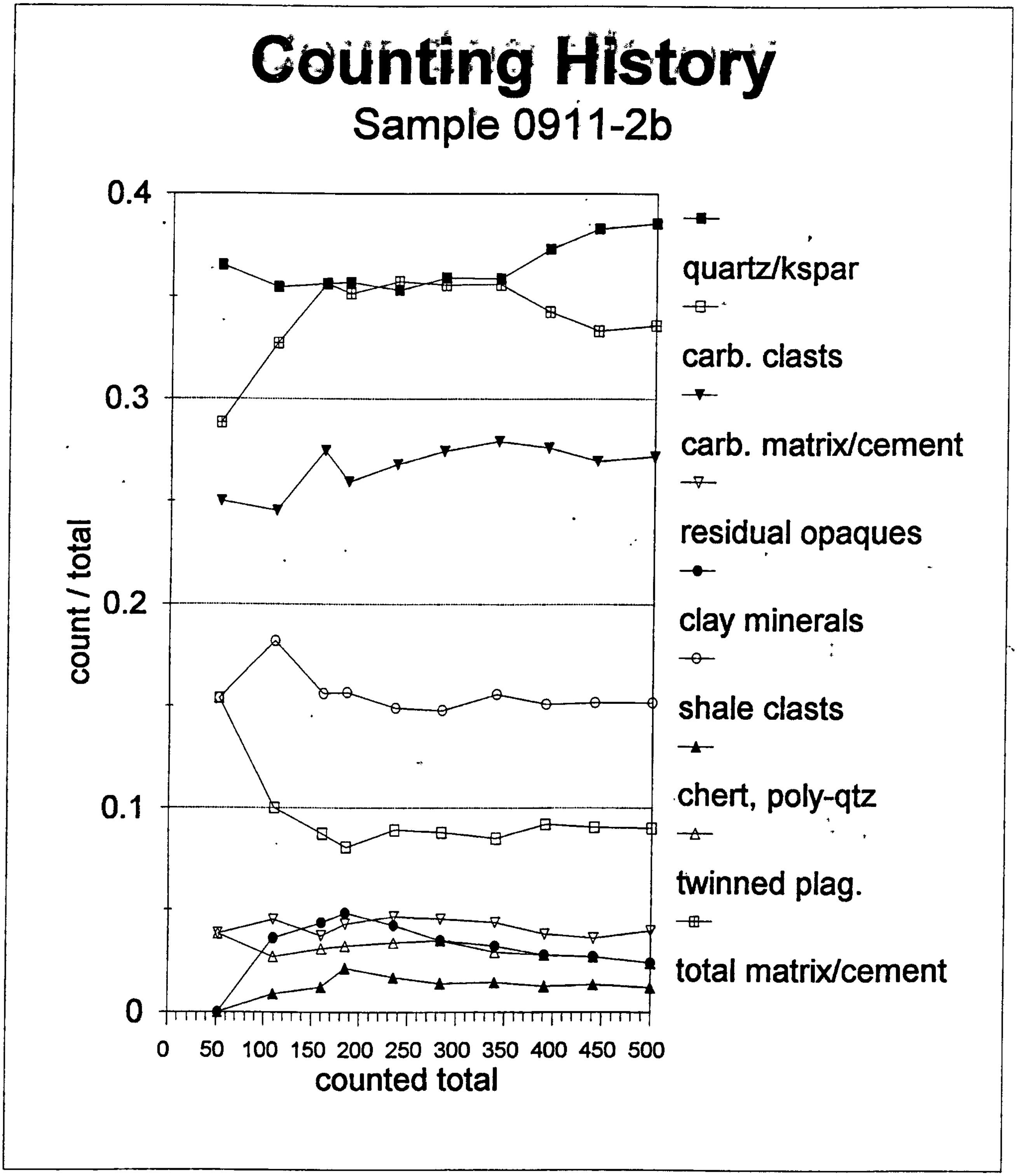

Figure A1-8 History plot of point counting data of sample 0911-2b indicating how final value for abundance stabilizes.

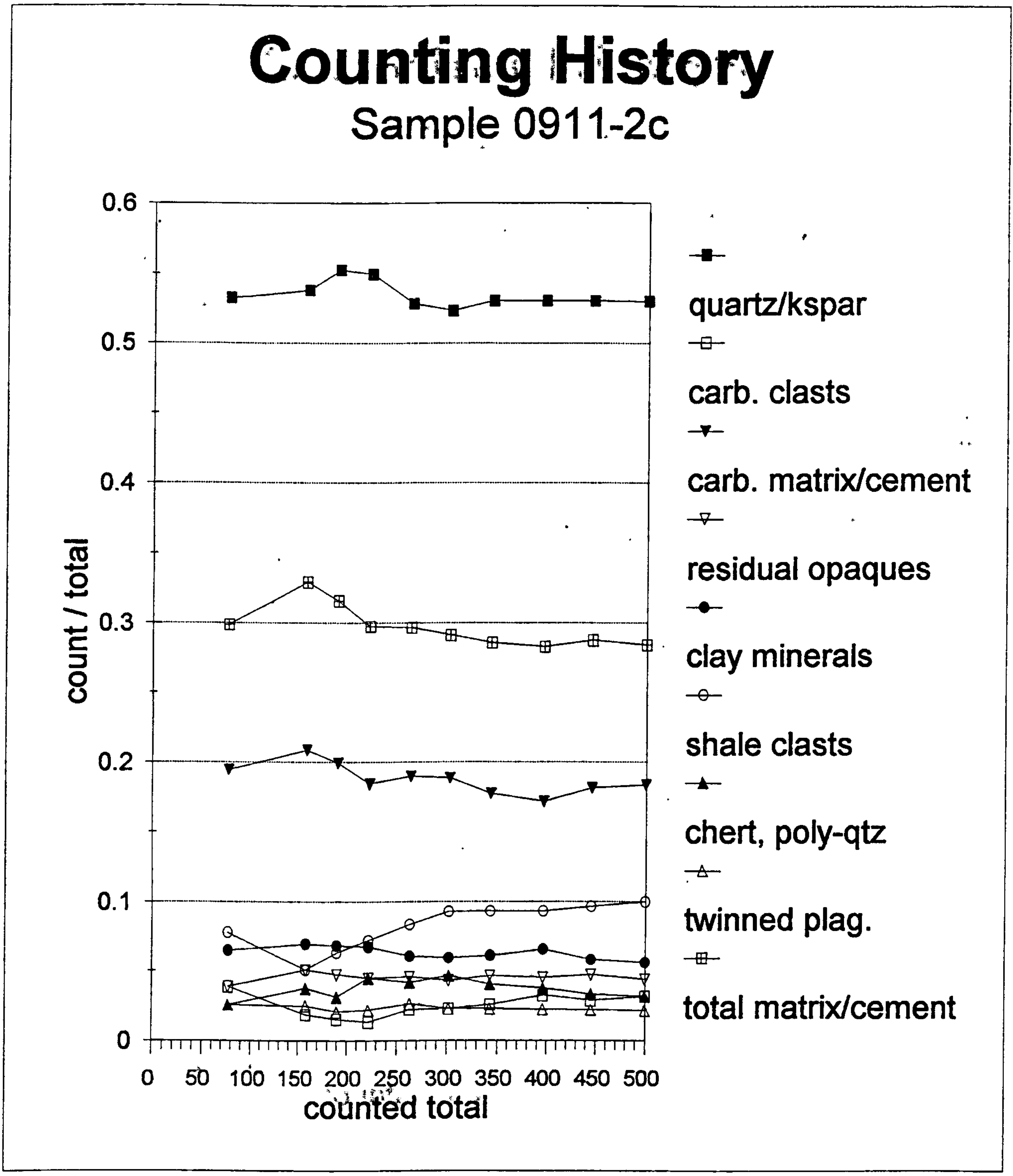

Figure A1-9 History plot of point counting data of sample 0911-2c indicating how final value for abundance stabilizes.

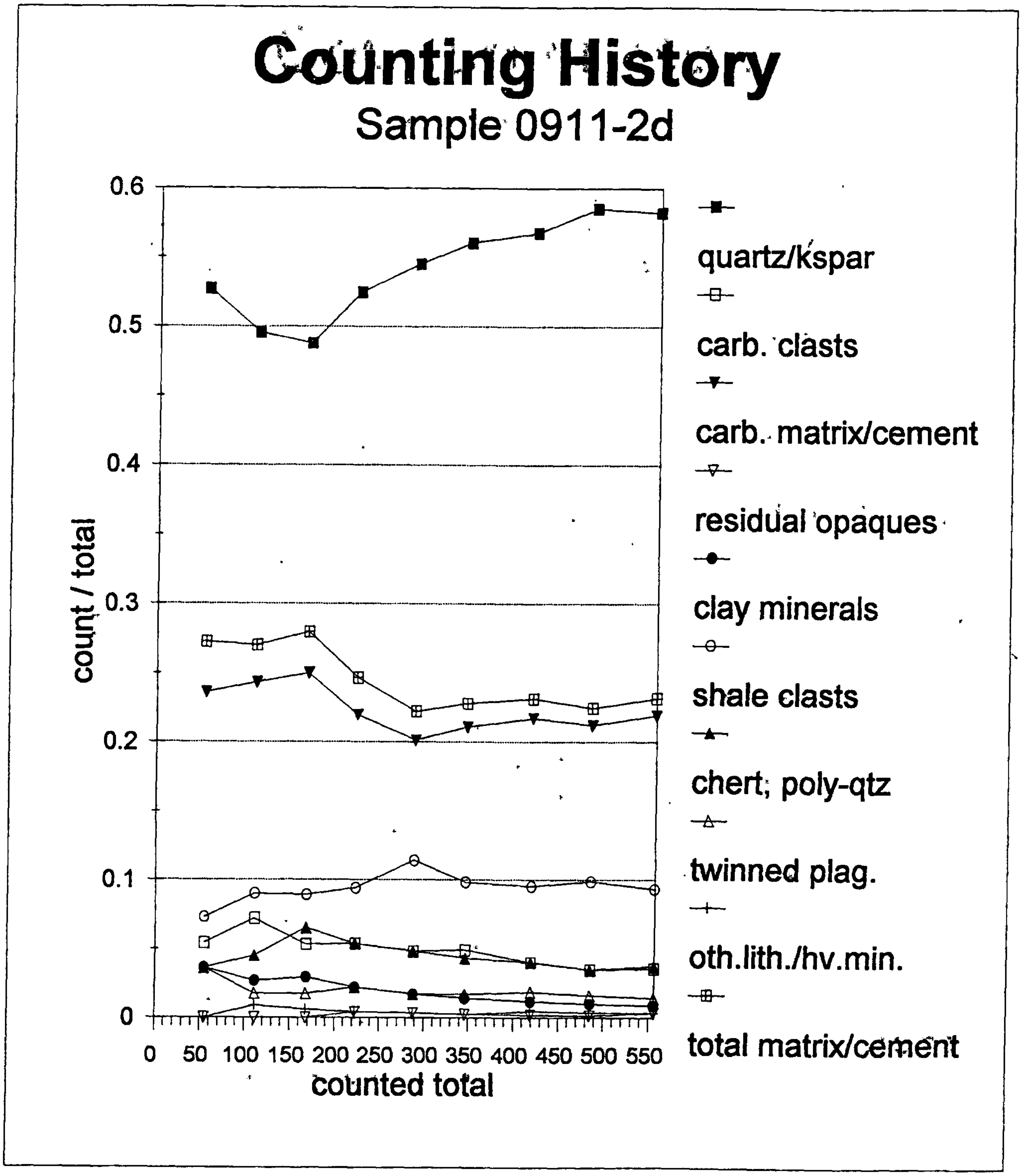

Figure A1-10 History plot of point counting data of sample 0911-2d indicating how final value for abundance stabilizes.

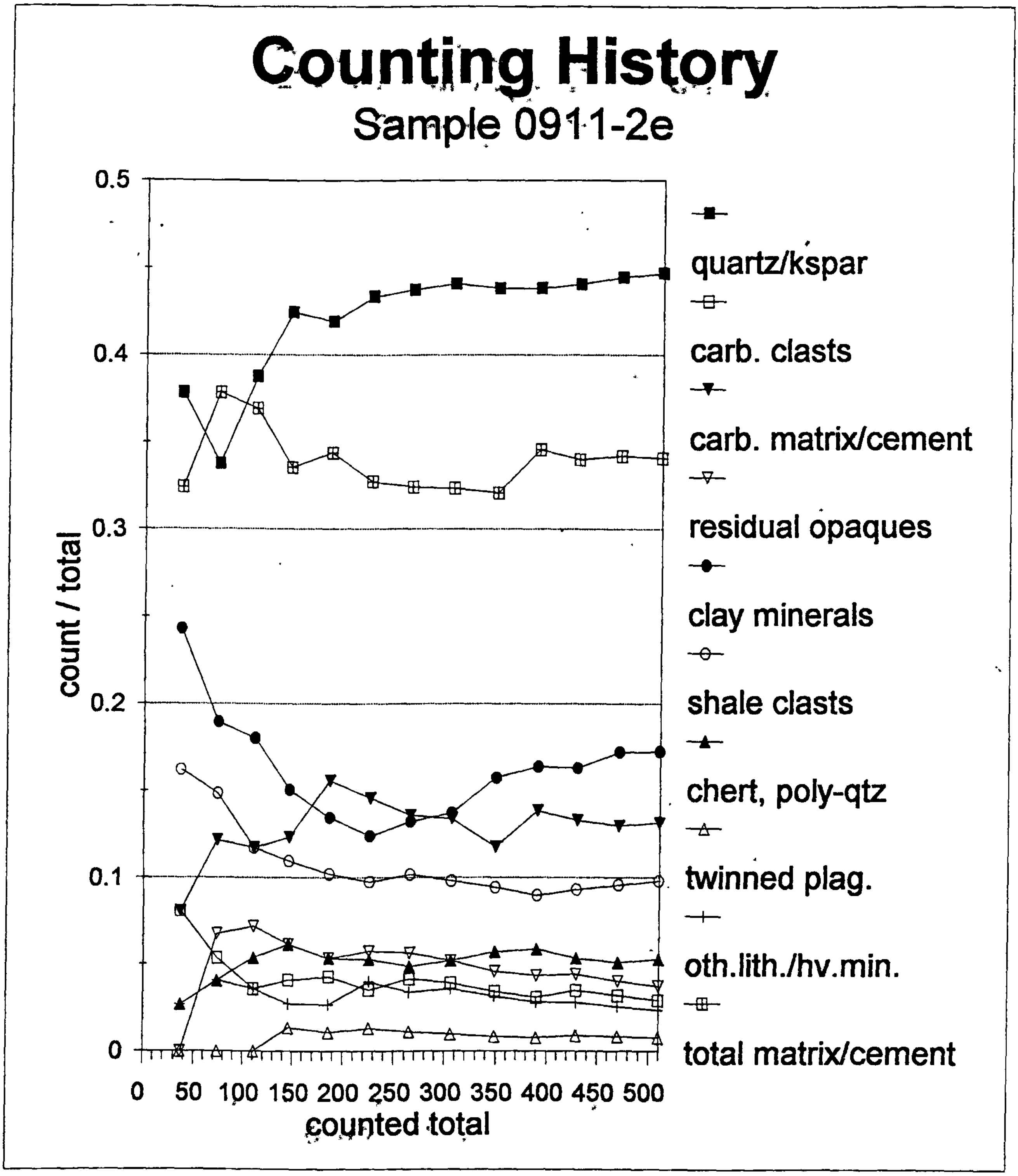

Figure A1-11 History plot of point counting data of sample 0911-2e indicating how final value for abundance stabilizes.

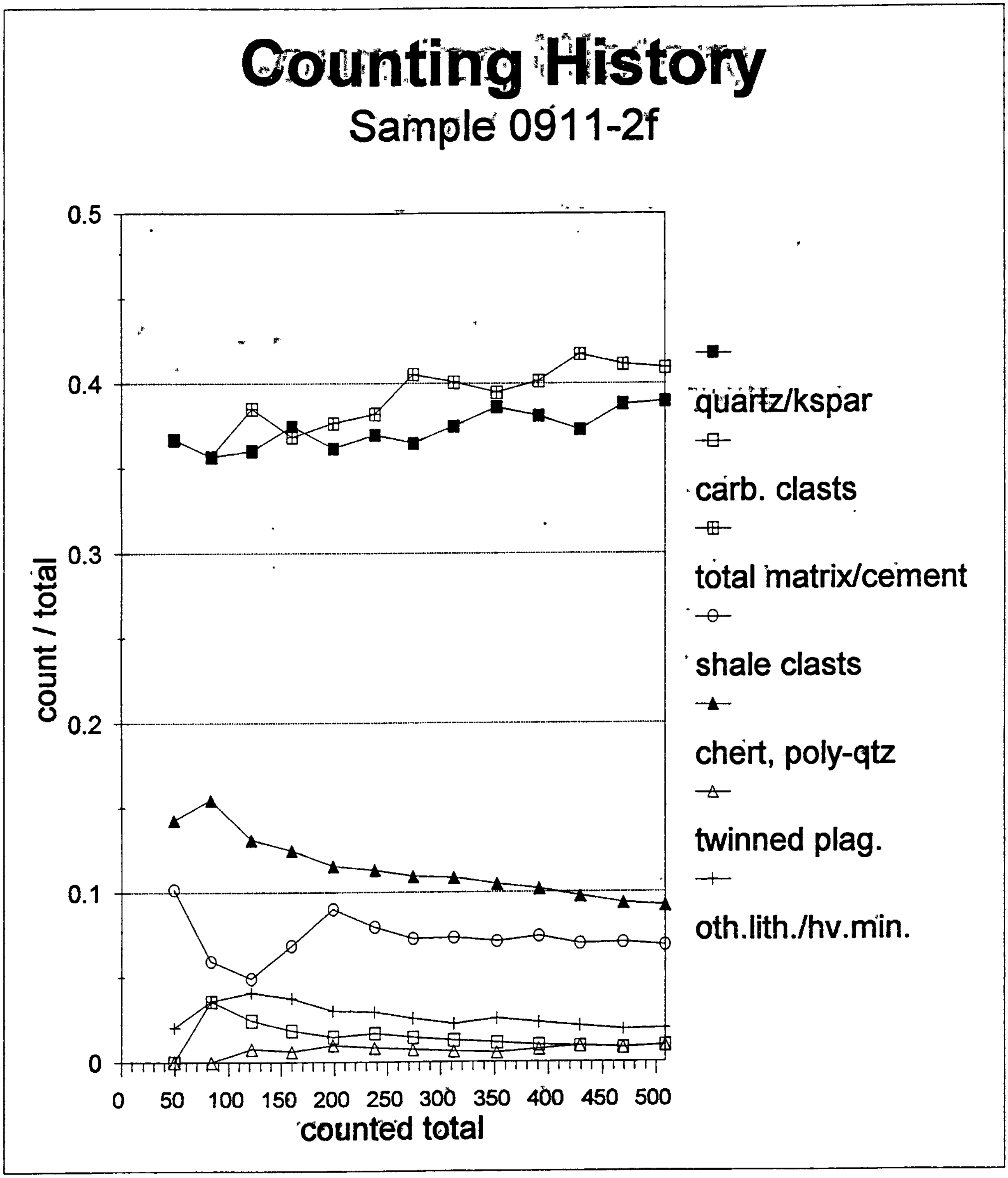

Figure A1-12 History plot of point counting data of sample 0911-2f indicating how final value for abundance stabilizes.

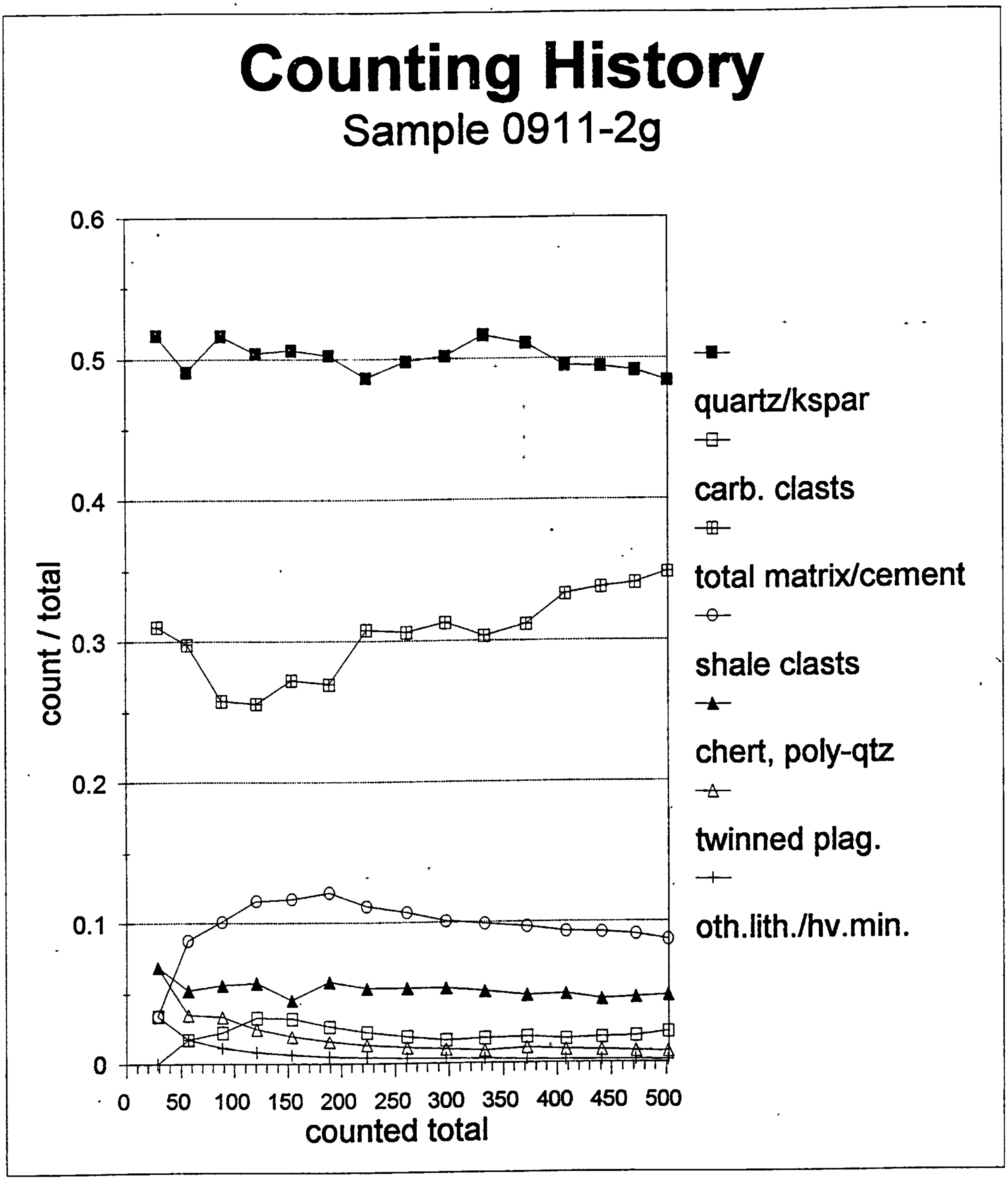

Figure A1-13 History plot of point counting data of sample 0911-2g indicating how final value for abundance stabilizes.

APPENDIX 2

ATTEMPT OF A QUALITATIVE RECONSTRUCTION OF PALEO-STRESS IN THE HGZ

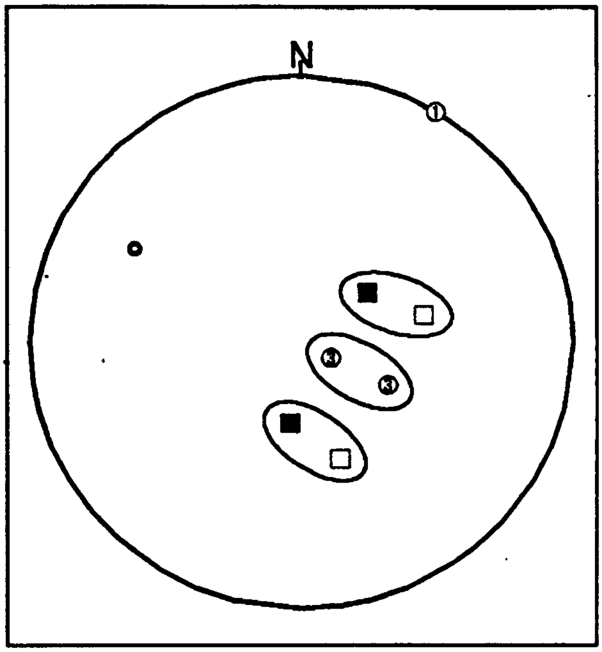

Figure A2 - 1 Poles to conjugate fractures (64); ○ : bedding; ■□ : estimates for cleavage; 1 : σ_1; 3 : σ_3 ; σ_2 is at about pole to bedding.

Conjugate, evenly spaced, planar fractures are nicely developed in interbedded fine grained greywackes at the most northern outcrop of the outcrop group 64 at the Interstate 87 bridge over the Mohawk River. Planar fractures seem to be continuous only within single beds. They do not appear in the thin interbedded shale. Offsets along fracture traces are not obvious. The mutual intersection of the fracture planes is about normal to bedding, here 030°/60°E, with a slight rotation towards a horizontal line. The normal of the plane which bisects the acute angle between the fracture planes trends about 120° and plunges steeply to the SE. The normal of the plane which bisects the obtuse angle between the fracture planes trends 030° and is horizontal. These directions may be regarded as the directions of minimum (σ_3) and maximum (σ_1) principal stress directions respectively (fig. A2 - 1) (Hobbs et al. 1976). The direction of the intermediate principal stress would be the fracture plane intersection. The missing observation of offset allows for exchange of the maximum and minimum principal stress directions. Another restriction of the interpretation of stress direction is the well developed layering defined by two lithologies with different mechanical properties and thicknesses. The theoretical background of the deduction of the stress directions from conjugate cleavage requires isotropic material (Hobbs et al. 1976). The influence of layering on failure plane-principal stress direction angle is not straightforward. The anisotropy, on the other hand, is only one-dimensional and the direction of change is nearly perpendicular to the inferred directions of σ_1 and σ_3. In this arrangement the anisotropic material may not behave much differently from isotropic material, because maximum and minimum principal stresses act only within the isotropic bedding planes. Also, the exclusive development of conjugate fractures in the greywacke may indicate that it is reasonable to focus on the greywacke beds as an isolated material and to view the inferred stress directions as valid only locally within the greywacke beds. The internal isotropy of the greywacke beds and the direction of σ_1 and σ_3 lying nearly within the bedding plane may explain the singular development of conjugate fractures within the greywacke beds at this location. The relation between the inferred stress directions and the regional structure is discussed next.

Relation of Conjugate Fracture to Regional Syncline

Both, the regional syncline and the outcrop-scale conjugate fractures allow for tentative reconstruction of directions of principal stresses, which may be related. One limitation for comparing them is immediately apparent, even without evaluating, e.g. the

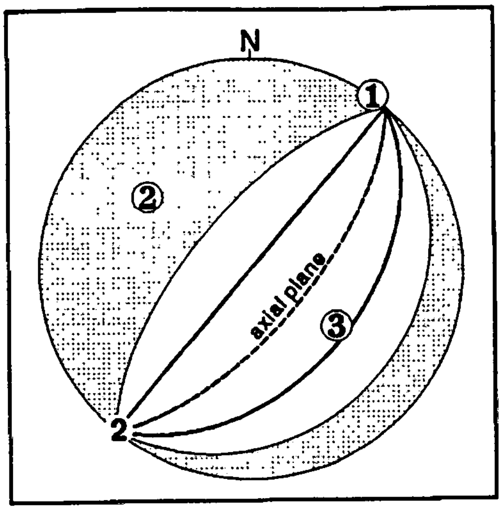

Figure A2 - 2 Schematic stereograph of stress directions inferred from fractures and fold. Circled numbers are stress directions from fracture, 2 is intermediate stress from fold. Shading shows range for maximum stress during folding.

different scales. It is, however, a customary assumption to expect larger scale features to have traceable effects on a smaller scale. The restrictions of the stress reconstruction from the conjugate fractures - anisotropy, missing offset - have been discussed. Concerning the folding, it seems rather straightforward to assume for simple folding that the attitude of the axial plane is a direct result of the governing stress field, with the direction of the maximum principal stress perpendicular to it, the direction of the minimum principal stress lying in it and the direction of the intermediate principal stress close to the hinge line. Changing material properties can significantly deflect these direction locally (see p.120, Means 1976). The quadrants centered about the axial plane, as shown in fig. A2-2 and fig. A2-3, are thought to be a least restrictive requirement for the directions of maximum or minimum principal stresses. Comparing stress directions inferred from the conjugate cleavage and from the regional fold

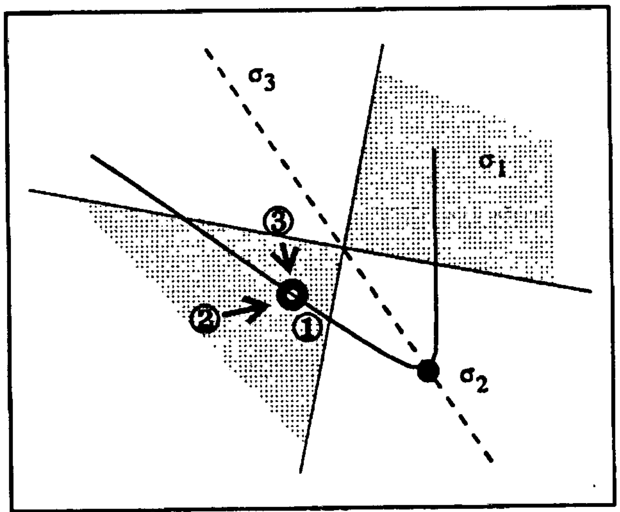

Figure A2 - 3 Inferred stresses in cross-sectional view. Circled numbers give stresses around conjugate fracture, sigmas give stresses during folding. Shading shows range for maximum stress during folding.

(fig. A2-2), it can be seen that both stress fields share the same set of directions, but the relative magnitudes at each direction disagree except for the minimum principal stresses, which are compatible. The directions of the maximum principal stresses differ by the largest angle possible, 90°, if the maximum stress during folding is placed near the pole of the axial plane. Disregarding possible imprecise measuring and plotting in view of the large discrepancy, the following conclusions may be reached:

a) the assumptions are not valid,

b) the assumptions are valid and

b1) the stresses are not related,

b2) the stresses are related and

b21) local stress directions are very different from regional stress directions or/and

b22) magnitudes of intermediate and maximum principal stresses are similar.

None of these conclusions can be discarded, as no additional information is available to this point. They are briefly discussed.

a) The assumptions about stress reconstructions are not valid. This conclusion is not very productive as it negates the whole approach and prohibits discussion of possible results, which on other grounds may later be shown to be not reasonable . Paleo-stress determination, even with much more sophisticated tools, is difficult and matter of investigation and debate (Schimmrich 1991). In the case of the conjugate fractures, the minimum and maximum principal stresses may be exchanged. In the case of the regional fold, a model as a simple fold is questionable as the fold may be the result of a whole stress history.

b) The assumptions about the stress reconstructions are valid. This complementary argument is necessary for further conclusions.

b1) The stresses are not related. This conclusion requires separate events. One structure may have been formed before or after the other. The fact that the reconstructed stress fields share the same set of directions of principal stresses, e.g. that the structural elements, on which the reconstruction is based, are closely related in their attitudes, may rather hint to a common reason for the origin of the conjugate fractures and the regional fold.

b2) In this case, the stresses are related. Other reasons for the large discrepancy are then:

b21) Local principal stress direction, based on the conjugate fractures, are just very different from the overall principal stress direction, based on the fold geometry. This conclusion is supported by the observation of local disturbances, e.g. unusual attitudes, near the occurrence of the conjugate fractures and the possibility of fault terminations nearby. This would, on the other hand, lead to a more random orientation of structural elements and not to the observed coincidence.

b22) Magnitudes of intermediate and maximum principal stresses are similar. A similar magnitude would explain the exchanged positions of these stresses in the two reconstructions and is a simple, and therefore favourable conclusion. It is questionable, however, if, given an oblate shape of the stress ellipsoid, a simple fold or conjugate fracture could develop at all. In the case of switched positions of maximum and minimum stresses reconstructed from the conjugate fracture, all three principal stresses become incompatible and the magnitude argument becomes worthless as it would result in a hydrostatic state of stress.

This brief discussion shows that any conclusion based on comparing principal stress direction must me be treated with great care. Even the most favourable conclusion leads to inconsistencies which force one to accept that there is no simple explanation.

APPENDIX 3

PRODUCING A DIGITAL BASE MAP

The availability of digitized topographic and road data triggered the decision to draw a base map with the aid of a computer. The main advantages are the ability to change fairly easily the geologic overlay of the map and the neat look. The used system comprises a standard IBM-compatible 486SX-25MHz, 4Mb RAM, 105Mb hard drive, 1Mb Trident8900 SVGA-Video card and a PanaSync C1381i monitor. Output was printed on a 300dpi HPLaserjet. A popular drawing package was used. Since such equipment is widely used and the digitized data is available for all states in the U.S. and in the public domain, the briefly described approach provides a quite general way to produce high resolution base maps for large areas efficiently.

Topography was included in the base map because it helps quickly locate features on the map and indicates major geologic boundaries. The Ordovician/Siluro-Devonian unconformity, the lowlands of the flysch belt, the Taconic Allochthon or the Marlboro Mountains, all are easily identified. Digital elevation models (DEMs) covering 1° quadrangles (Scranton, Albany_east, Albany_west, Hartford) were electronically retrieved from a remote USGS archive via the Internet (ftp edcftp.cr.usgs.gov or via www, URL: http://sun1.cr.usgs.gov/glis/hyper/guide/1_dgr_demfig/index1m.html, valid August 1994). These DEMs are huge text-files (about 8Mb) which contain in a certain order altitudes with a spatial resolution of 3 arc-seconds corresponding to 93m in N-S direction and 69m in E-W direction at the latitude (42°N) of the map area. Because of insufficient computing power it was unfeasible to produce contours from the gridded data. It was found that a shaded relief type representation of topography visualizes well all resolved topographic features if topography is artificially steepened. Such a representation was produced by processing the DEM raw data with the public domain program Microdem (Guth 1991, available by anonymous ftp to ftp.blm.gov, location /pub/gis/microdem.zip, valid August 1994) after slight, but necessary changes in the header of the raw DEM files. The 1° areas were divided in 16 15' subsets each and the relevant 17 subsets processed. The resulting pixel-based grey-scale pictures were "bleached" with standard image processing software to become a less intrusive backdrop for the basemap.

The road network and hydrographic features were added to help exactly locate outcrops and actually find them. Digitized road and hydrographic data were available in the USGS digital line graph (DLG) format on a CD-ROM which can be borrowed from the local university library. These data are of the vector (line) type and are digitized from the printed 1:24000 topographic maps. The resolution is high and minor dirt roads included. After extracting the data from the CD-ROM in 15' sets they were converted to a standard vector format (DXF) for further processing by a USGS public domain program (DLGACAD, supplied with CD-ROM). In order to overlay the road network on the topography it was necessary to scale the road sets and rotate them by 0° to 3°, because DLG data refer to the UTM coordinate system, whereas DEM data refer to the geographic coordinate system. As this rotation was done by hand slight inconsistencies may be visible for example for rivers. In some areas (cities) high density road networks were removed as unnecessary overhead challenging computing power and user patience.

References

Guth, P.L., 1991, Microcomputer application of digital elevation models and other gridded data sets for geologists, *in* Merriam, D.F. and Kürzel, H., [eds.], Use of microcomputers in geology, Plenum Press.