Provenance Study of the Middle Ordovician

Sandstones of New York and Western Vermont

Abstract of

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ABSTRACT

Medial Ordovician rocks exposed in westernmost New England and eastern New York State include thick sequences of marine sandstones which are part of a belt extending from Newfoundland to Tennessee. A petrographic study was made of 237 samples distributed across the entire outcrop belt (approx. 250 km. north-south along strike and 190 km. east-west across strike).

Two distinct types of sandstone are recognized, the oldest, and most wide spread, is a deep water lithic wacke deposited by turbidity currents and found interbedded with shale (flysch). The younger sandstone is found only in the southeastern part of the study area and is a lithic to quartz arenite which was deposited in a shallower water environment (molasse).

The composition of these sandstones is mainly quartz (50-70%) along with minor amounts of chert, feldspar and lithic fragments all in a varying amount of matrix and cement. The lithic fragments (7-12% of a given sample) are mainly sedimentary (shale, siltstone, greywacke and sandstone) with minor amounts of metamorphics (phyllite, slate and schist), carbonates, volcanics (silicic to mafic) and volcaniclastics. No minerals indicative of medium to high grade metamorphism were found.

Paleocurrent evidence suggests that the oldest flysch was deposited from the east in a number of small overlapping fans while the younger flysch and the molasse appear to be part of a single large fan whose source is to the south. Along strike no significant change in

composition is seen but across strike as the flysch grows younger an increase in K-feldspar and carbonate material is noted with the greatest increase occurring in the molassic sediments.

These clastic sandstones were deposited in an elongate basin which formed as the result of and arc-continent collision during the Taconic Orogeny. The flysch sands are thought to be derived from recycled continental rise sediments (eg. Taconic Allochthon) with a contribution of volcanics and volcaniclastics from the colliding island arc. The lack of ophiolitic detritus indicates ophiolitic obduction either did not take place or occurred to a much lesser degree than in the northern extension of this belt in Canada. The increase of K-feldspar and carbonate may indicate the progressive exposure of Grenville basement and covering shelf carbonates, by overthrusting.

ACKNOWLEDGEMENTS

The idea for this project arose out of discussion with my main advisor Bill Kidd and fellow graduate student Dave Rowley. I would like to give thanks to my thesis committee of Bill Kidd, George Putnam, and especially Dwight Bradley to whom I am deeply indebted for his being immensely helpful both as an advisor and as a friend. My fellow graduate students, Lauren Bradley, Keith Mahon, Grant Cushing, Jane Kozinski, Bill Shaw, Tom Ray and Peter Hall amongst others, all gave freely of their time and will always be remembered for their friendship.

Foremost I would like to express my graditude to my parents, Francis and Emily Tanski, who always gave their support freely and willingly and most of all for instilling in me the desire for education and love of knowledge without which this thesis would not have not been possible.

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CHAPTER ONE

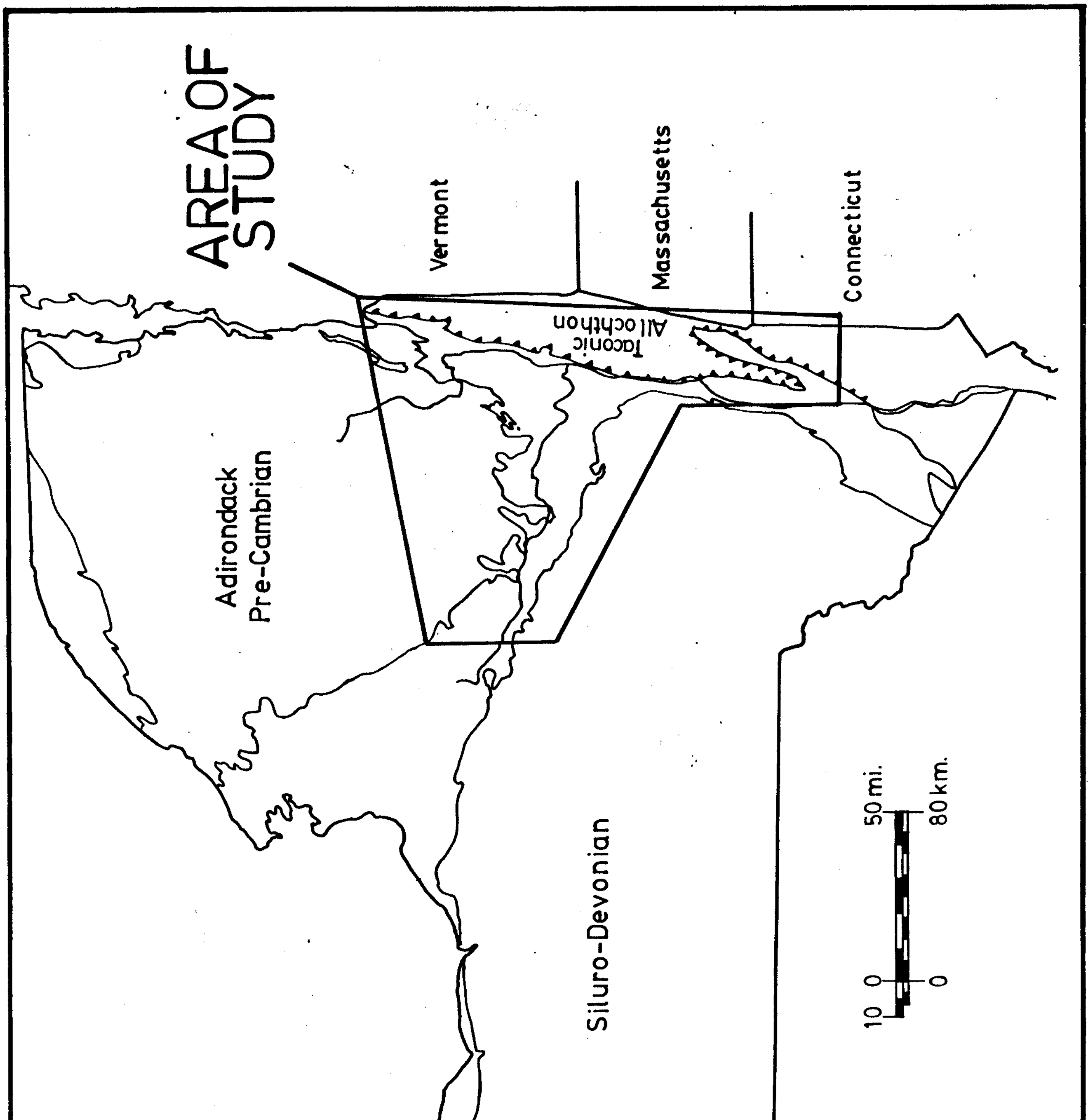
INTRODUCTION

Medial Ordovician rocks exposed in westernmost New England and eastern New York State include thick sequences of marine sandstones which are known to be part of a belt extending from Newfoundland to Alabama. Two different environments of deposition are identified for the sandstones; most are deep-water, interbedded with shale, while some are from a shallower environment. The deep-water sandstones show features characteristic of deposition by turbidity currents, while the shales are typical marine sediments. Deposits of this type are commonly associated with orogenic belts and the term flysch has come to be used to describe this facies association.

The area covered in this study is located in eastern New York State extending north-south along the New York-Vermont border from Granville to Poughkeepsie and east-west from Albany to Utica (fig 1.1). Rocks seen in this area vary in degree of deformation from folded, thrusted and transported (eastern section) to flat lying and undeformed (western section).

This study was undertaken to determine the provenance of the clastic detritus contained within the Ordovician sandstones. Sedimentary detritus is often the only source of information which we have to examine past tectonic activity. Studies by Dickinson and Suczek (1979) on modern marine sandstones from known tectonic environments have

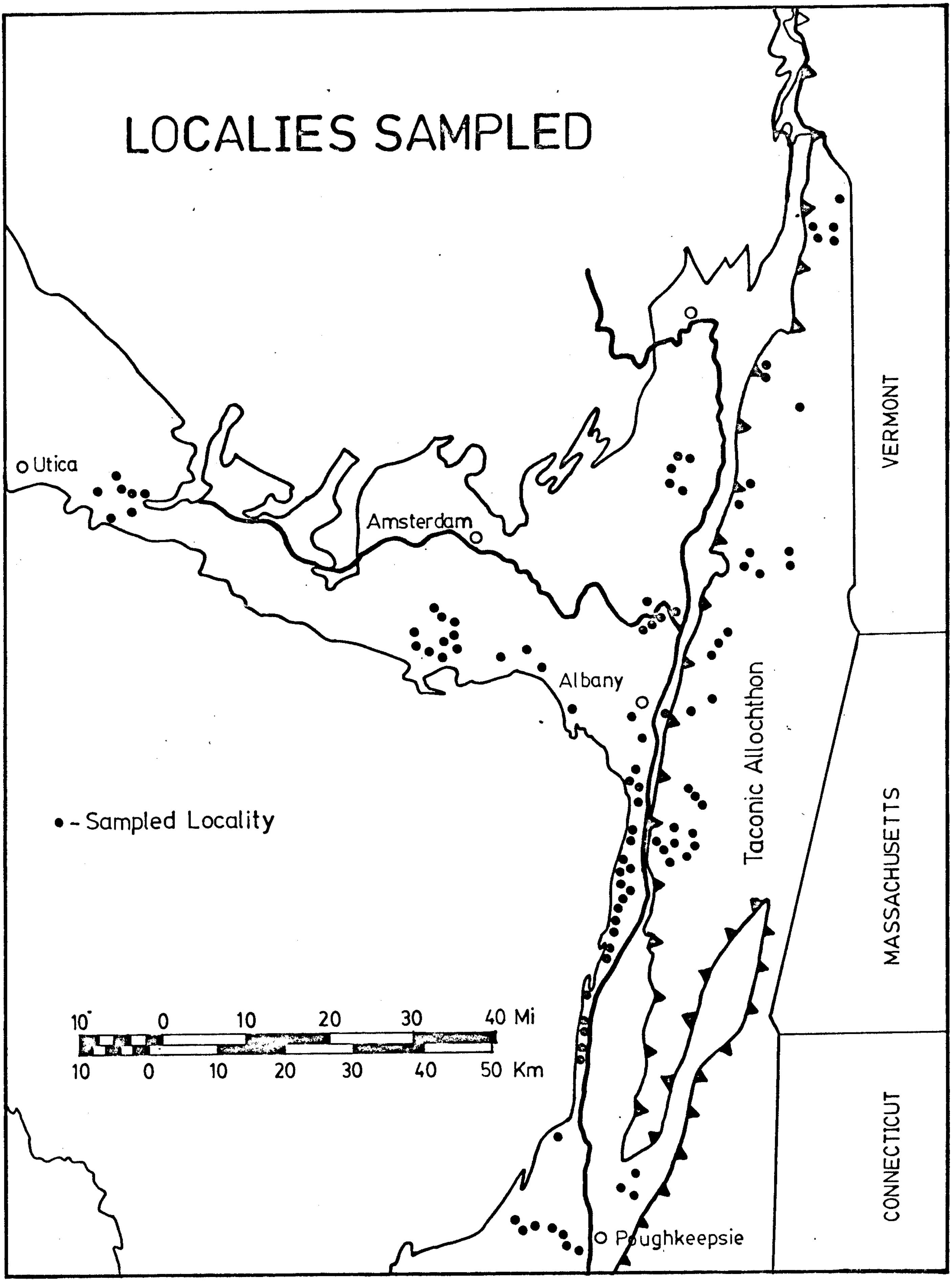
Figure 1.1 Locality map showing area of study (outlined area).


AREA OF STUDY
Vermont
Massachusetts
Connecticut
Taconic Allochthon
Adirondack Pre-Cambrian
Siluro-Devonian
50 mi.
80 km.
10 0
0

demonstrated a relationship between the detrital modes of sandstones and the tectonic processes through which they were created. Similar studies of ancient sandstones are ideally able to yield information on source area, its composition and the tectonic processes which were active at the time of deposition. A systematic strategy for determination of this information has evolved under the general heading of provenance study. Potter and Siever (1956) outlined a methodology which concentrates on the examination of directional structures and petrographic features which in past studies have yielded the most information for the effort involved. Directional structures are often easily found and readily interpreted features in sandstone and give information on local transport direction of sediment and, perhaps, the general location of the source area. The data gathered through petrographic study is used to map regional mineral associations which, combined with directional structures, allow inferences to be made about the regional paleogeography and may place constraints on tectonic models.

The approach taken to data collection in this thesis can be divided into two broad categories, field scale and thin section scale. Field work included the study of stratigraphic sections, measurment of paleocurrent indicators and the collection of samples. Approximately 300 samples were collected during the field phase from which 237 thin sections were made. The samples were collected from approximately 100 separate locations (fig 1.2 and plate 1). These were chosen to ensure as complete a geographic and stratigraphic sampling as possible. It was of particular interest to obtain complete suites of samples of similar age along strike and samples of different ages across strike. Work performed on the thin sections included point counting, grain size

Figure 1.2 Map showing localities sampled.


LOCALIES SAMPLED
Utica
Amsterdam
Albany
Poughkeepsie
Taconic Allochthon
VERMONT
MASSACHUSETTS
CONNECTICUT
• - Sampled Locality
10 0 10 20 30 40 Mi
10 0 10 20 30 40 50 Km

measurement, quartz undulosity measurements, staining of feldspars and textural studies. A more detailed discussion of methodology is given in following chapters.

CHAPTER TWO

GEOLOGIC SETTING

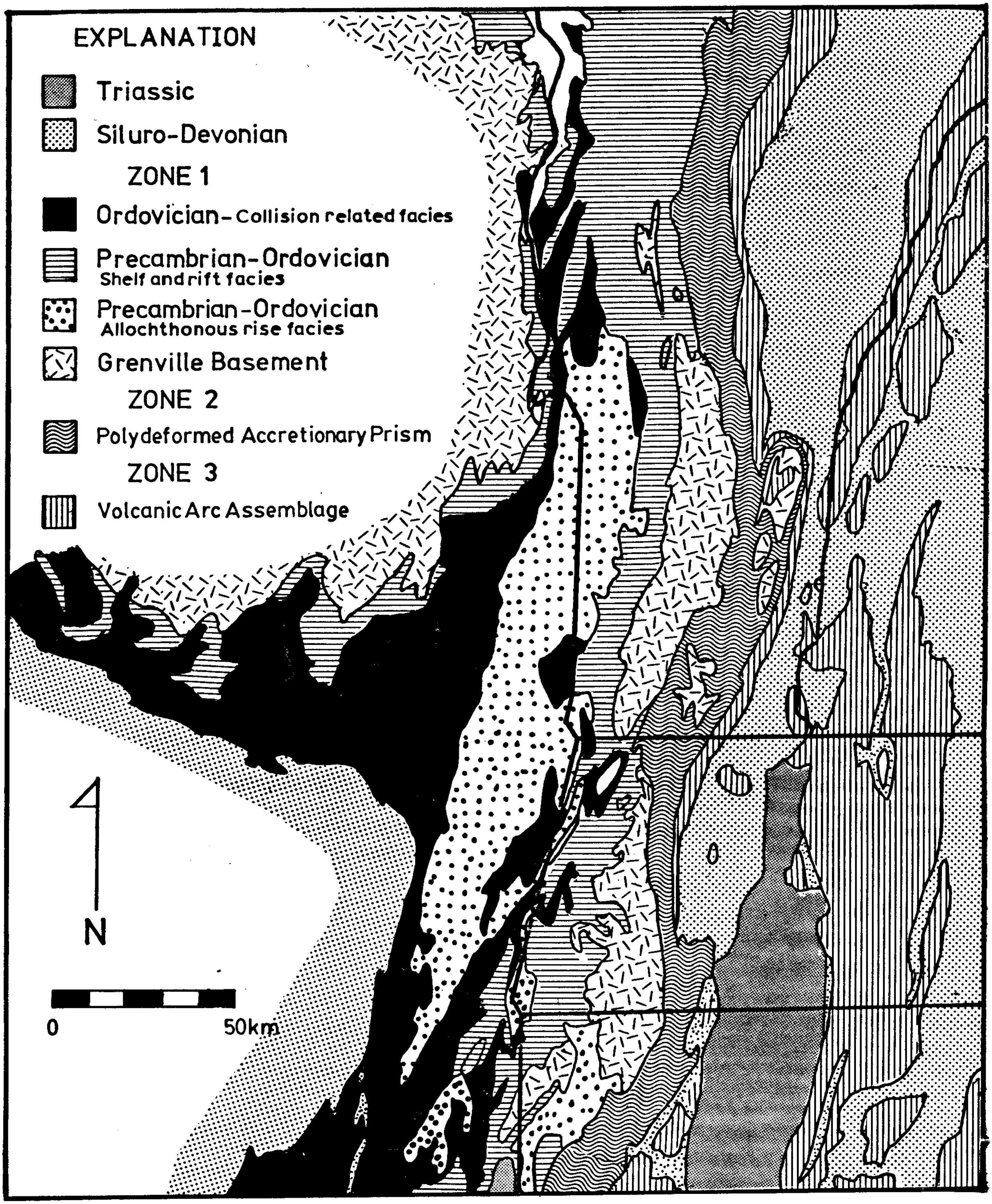
Three major tectono-stratigraphic regimes can be identified in the pre-Silurian rocks of western New England: a carbonate shelf, an accretionary prism and a volcanic arc. These are the three zones as described by Rowley and Kidd (1981) and are briefly discussed here (fig 2.1).

The first zone consists of Grenville basement unconformably overlain by Cambrian age arkosic and feldspathic sandstones in turn covered by an eastward thickening sequence of largely dolomitic carbonates. Upon the carbonates are deposited Ordovician limestones (Trenton Group) which in turn are overlain by deepwater shale (Canajoharie shale). A sequence of deepwater sandstones and shales (Schenectady/Frankfort) rests conformably on the shales and in two places can be seen to grade up into relatively shallow water sandstones (Quassaic, Oswego, Pulaski).

Thrusted from the east onto the carbonate shelf sequence is the Taconic Allochthon (Zen 1967), consisting of deepwater sediments with continental rise affinities (Dewey and Bird 1970) and stratigraphic equivalents of the carbonate shelf on which they are now thrust.

Zone 2 contains multiply deformed and metamorphosed schists, phyllites and gneisses which are considered to be part of an accretionary prism. Also seen are serpentinized mafics and ultramafics

Figure 2.1 Diagram showing distribution of tectono-stratigraphic regimes of western New England (adapted from Rowley and Kidd 1981).


EXPLANATION
Triassic
Siluro-Devonian
ZONE 1
Ordovician- Collision related facies
Precambrian-Ordovician
Shelf and rift facies
Precambrian-Ordovician
Allochthonous rise facies
Grenville Basement
ZONE 2
Polydeformed Accretionary Prism
ZONE 3
Volcanic Arc Assemblage
N
0
50km

and glaucophane bearing amphibolites that are interpreted as being pieces of a dismembered ophiolite.

Zone 3 is a volcanic arc terrane and consists of metamorphosed felsic and mafic volcanics, volcaniclastics and plutons of intermediate composition. These volcanics are intruded into and deposited onto rocks of late Precambrian to Cambrian age.

SANDSTONES

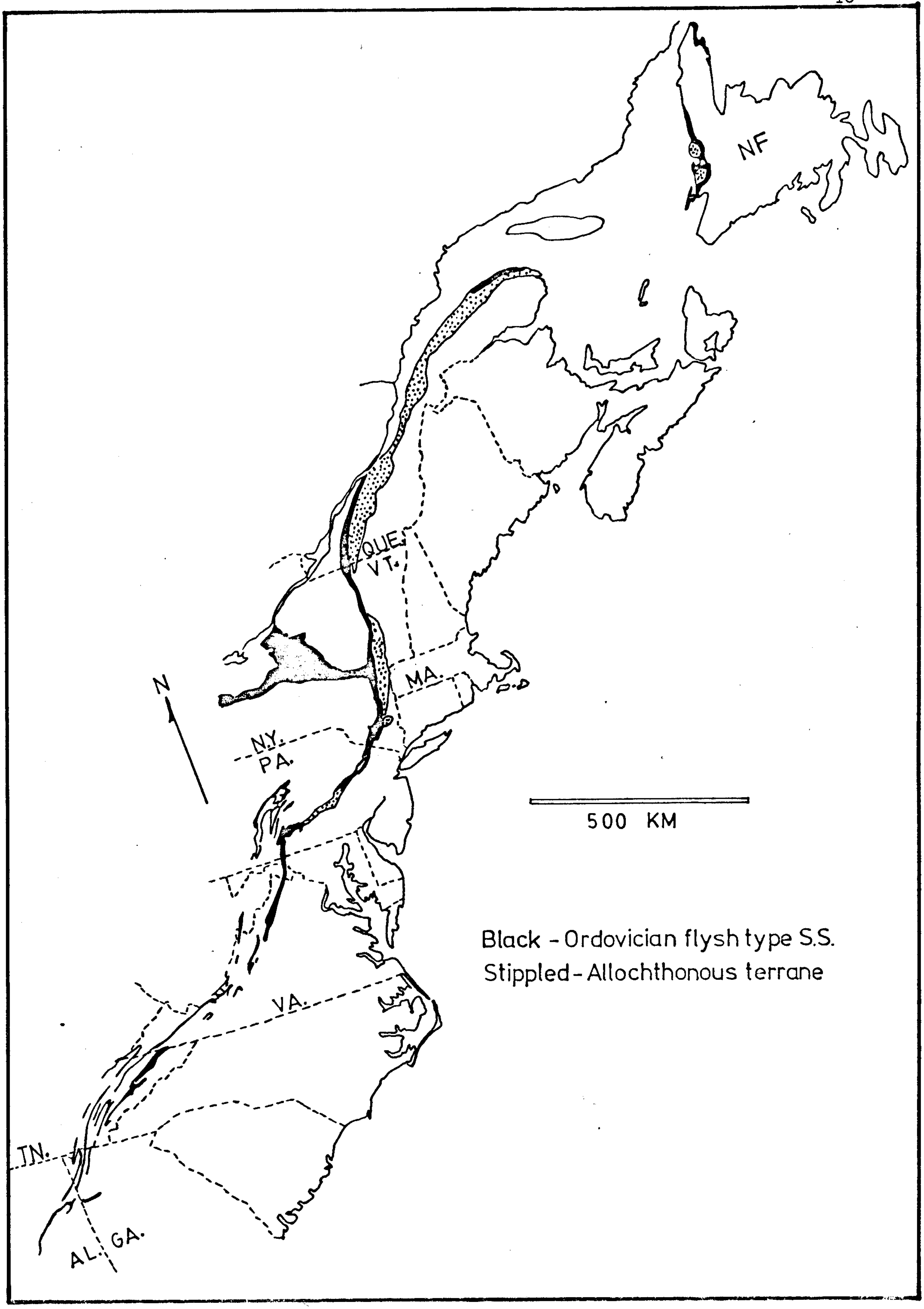
REGIONAL RELATIONSHIP

The medial to upper Ordovician flysch of New York and western New England is part of a narrow belt that outcrops almost continuously from Newfoundland to Alabama (fig 2.2). Various sections have been the subject of studies to determine the sedimentological and tectonic implicaations of these units (Hiscott 1978, Enos 1969, Belt et al 1979, Middleton 1965, McBride 1964, Shanmugan and Walker 1978). A similar stratigraphic sequence exists along the length of the belt whereby shale deposited above a subsiding carbonate shelf sequence grades upward into turbiditic sandstones.

The Caradocian sandstones of New York State and western New England can be divided into two broad categories: those of deep-water origin which are interbedded with shales (flysch), and those which are of a shallower marine depositional environment.

FLYSCH

Figure 2.2 Map showing distribution of Ordovician flysch type sandstones (solid) and allochthonous terranes (stippled) (Bosworth and Vollmer 1981).


NF
QUE.
VT.
MA.
N
N.Y.
PA.
500 KM
VA.
TN.
AL.
GA.
Black - Ordovician flysh type S.S.
Stippled - Allochthonous terrane

The flysch facies rocks in the study area are Caradocian in age and range from the Diplograptus Multidens to Climacograptus Pygmaeus (Riva 1974) graptolite zones. As in other parts of the flysch belt the carbonate shelf is overlain by deepwater shale which passes upward into the sequence of shales and turbiditic sandstones. The shale-flysch contact becomes younger moving from east to west, evidence that the flysch migrated across the carbonate shelf of Ordovician North America from east to west. Contemporaneous with flysch deposition is the emplacement of allochthonous terranes found in Newfoundland (Humber Arm and Hare Bay Allochthons, Rodgers and Neale 1963, Stevens 1970), Quebec (Nappes of Quebec, St. Julien and Hubert 1975, Hiscott 1978), New England (Taconic Allochthon, Zen 1967) and Pennsylvania (Hamburg Klippe, Wright et al 1979).

The middle Ordovician sandstones associated with the Taconic Orogen are contained in several different formations. The Pawlet and Austin Glen formations are the easternmost flysch sediments and moving westward the flysch becomes known as the Schenectady and Frankfort formations (Fisher 1977). A confusing combination of lithostratigraphic and biostratigraphic criteria has been used to define these formations which tends to make for unnecessary complications. A simpler scheme for grouping these rocks based on their stratigraphic relationship with the underlying lithologies was suggested by Kidd (1984). I will briefly outline the past work on these formations then discuss and define the formations as they are used in this thesis.

The flysch of Eastern most New York and western Vermont is contained within the Taconic Allochthon and was initially described by Dale (1899) as being part of the Hudson Grits. Ruedemann (1901) originally included these units in his Normanskill Formation which he defined as those rocks containing Normanskill graptolites (defined by Hall (1847) with species added by Ruedemann). Ruedemann (1942), while working in the Catskill area, noted two distinct lithologic types within the rocks containing the Normanskill graptolites. The lower unit consists of shale and chert and was named Mt. Merino while the upper unit, consisting of shales and greywacke, was named the Austin Glen (Ruedemann 1942). Schumaker (1960) and Zen (1961) proposed the name Pawlet for the correlative rocks in the northern part of the Taconic Allochthon.

The flysch found to the west of the Taconic Allochthon ranges from that which is complexly deformed by folding and thrusting (Austin Glen and eastern Schenectady formations) to that which is essentially flat lying (western Schenectady and Frankfort formations). These are the rocks which were originally named the Hudson River Group by Mather in 1843 (Walcott 1890). More recent work by the New York Geological Survey (Austin Glen: Ruedemann 1942, 1970; Schenectady: Ruedemann 1912; Frankfort: Kay 1953) has given these formations their current identities.

The oldest section is the Austin Glen, Orthograptus Ruedemanni to C. Spiniferus (Riva 1974), which shoud not be confused with the older, D. Multidens, Austin Glen of Taconic Allochthon association.

The Schenectady Formation was defined by Ruedemann (1912) as the interbedded impure sandstones and black shales found around Schenectady, New York. Rickard and Fisher (1973) assigned this formation to the Climacograptus spiniferus graptolite zone. Hartnagel (1912) first correlated the Schenectady Formation with the Frankfort Formation found to the west. Fisher (1962) demonstrated the time-transgressive nature of the Schenectady and Frankfort Formations.

The Frankfort Formation was originally called the Frankfort Slate by Vanuxem (1840) and marks the westernmost transgression of the flysch. The Frankfort is in the C. Pygmaeus graptolite zone at the type locality (along Moyer Creek, Frankfort, New York) and becomes older to the east where it grades into the Schenectady.

The proposed redefinition of these formations combines all the flysch associated with the continental rise sediments of the Taconic Allochthon (Pawlet and Austin Glen Formations) into the Pawlet Formation. The Austin Glen Formation is defined here as the folded and thrusted rocks found to the west of the Taconic Allochthon whose relationship to the underlying formations is uncertain, eg. whether they are in structural or stratigraphic contact. The Schenectady/Frankfort Formation includes all the flysch to the west of the Austin Glen formation which is in stratigraphic continuity with the Canajoharie Shale. The detailed relationships of the flysch with the underlying formations is covered in Chapter 3.

SHALLOW WATER SANDSTONES

The shallow water sandstones are located in the southern part of the area studied and are part of the Quassaic Formation (Fisher 1970). The most recent work on these sandstones has been performed by Russell Waines and much of my knowledge of the past work done in this area has been derived from his field trip guide (Waines, et. al. 1983).

The Quassaic Formation lies in the Mid-Hudson Valley between Kingston and Newburgh. These rocks of Ordovician age were initially included in Mather´s Hudson River group (1843) and no further significance was given to them until Fisher (1969) noted the presence of a ´molasse´ consisting of red and green quartzites which he reported to be conformable on the Austin Glen.

Bird and Dewey (1970) named this sequence of sandstones the Illinois Mountain Molasse. Fisher et. al. (1971) introduced the term Quassaic Quartzite for the "thickbedded red and green quartzites and greenish grey shales, conglomerates with pebbles of red and black chert, shale and limestone" which conformably overlies the Austin Glen. Fisher (1976) further defined the Quassaic sequence as a proximal shelf, marine, terrigenous facies lying conformably on the Snake Hill Shale.

The most recent work has been done by Waines et. al. (1983) who have described the stratigraphy in the greatest detail so far. Their work indicates there are more than 3000 meters of sandstones which are from late medial to medial late Ordovician in age.

CHAPTER THREE

DETAILED LITHOLOGIES

Pawlet

This is the uppermost unit of the Taconic Allochthon and is conformable to disconformable with the underlying rock units. The outcrops sampled are all from the Giddings Brook slice (Zen 1961) of the Allochthon. The contact between the Pawlet and the formations lying beneath has traditionally been interpreted as an unconformity (Zen 1961, Shumaker 1967, Bird 1969). Recent work by Jacobi (1977) and Rowley et al (1979) in the area near Granville, New York has shown the Pawlet to be conformable with the underlying Mt. Merino and further to the east the contact with the Poultney is interpreted to be at most a disconformity (Rowley 1980).

The lowermost Pawlet is distinguished by the appearance of thin beds (1-2 cm.) of fine grained greywacke interbedded with black shale, which dominates. The greywacke beds quickly become more prevalent and thicker (ranging in size from 10 cm. to 1 meter in thickness) and comprise approximately 60% of the outcrop (fig 3.1). The thinner greywacke beds have sharp upper and lower contacts with the surrounding shale while the thicker beds generally show a sharp upper contact with a lower contact having sedimentary structures typical of a turbidite deposit. The bottom few centimeters of the thicker beds in places show concentrations of shale rip up clasts.

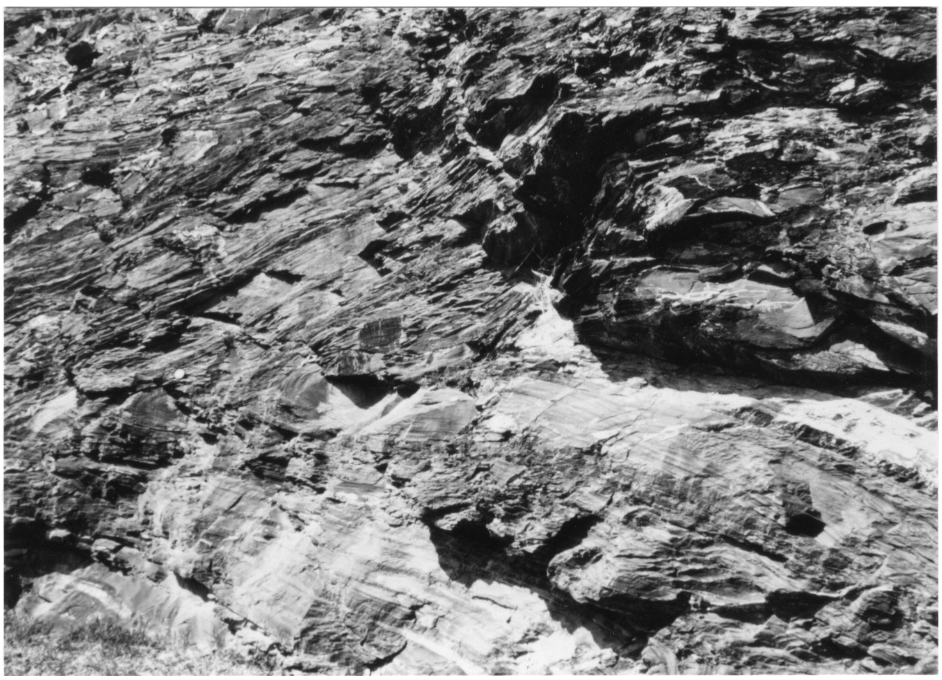


Figure 3.1 Outcrop of folded Pawlet Formation located on Route 22 north of junction with Route 67, north of Hoosick Falls, New York.

The unweathered surface of the greywacke is medium to dark grey with the weathered surface being medium grey to brownish in color. The shale is dark grey to black on both unweathered and weathered surfaces. The shale is very fine grained and generally well cleaved. The greywacke grain size ranges from fine (thin beds and upper parts of the thicker beds) to coarse. The greywacke is much harder and is affected less by weathering than the shale, which causes the shale to be recessed when seen in outcrop.

The top of the Pawlet is erosional and estimates of thickness range from 100 meters (Shumaker 1967) to 300 meters (Potter 1972) but due to extensive folding and faulting it is difficult to make a precise estimate of formation thickness. The longest continuous section personally seen is located along the Kinderhook Creek at Rossman Falls and is approximately 100 meters thick.

The Pawlet contains graptolites (Rickard and Fisher 1973, Rowley 1980) which place it in the upper Nemagraptus gracilis to lower Diplograptus multidens graptolite zones (Riva 1974).

Austin Glen

The Austin Glen is very similar in outcrop appearance to the Pawlet rock. The significant differences are the fauna found in it, graptolites (Rickard and Fisher 1973) placing it in the upper O. Ruedemanni to lower C. Spiniferus zones, and the fact that, due to the extensive folding and thrusting, there is a degree of uncertainity as to what the stratigraphic relationship of this formation is with the underlying strata. Considering its location it could have been originally deposited on shelf carbonates or deep water shales.

The greywacke beds vary in thickness from a few centimeters to 2 meters with the dominant thickness being approximately .5 meters. The percentage of the outcrop which is greywacke varies from 40-60 % (fig 3.2 and 3.3).

Schenectady/Frankfort Formation

The Schenectady and Frankfort Formations have been treated separately in the past but, here, due to their time-transgressive nature and the difficulty in describing criteria for differentiating them they will be treated together as a single formation. The Schenectady Formation conformably overlies the Canajoharie Shale and is in the C. Spiniferus graptolite zone . The greywacke and shale bear the same physical characteristics as in the previously described formations with the main distinction being the great variation in both the thickness of greywacke beds and in the percentage of greywacke found in an individual outcrop. The greywackes of the Schenectady become thinner bedded and the unit contains a greater percentage of shale as one moves from east to west in the Formation. Along with these changes the greywacke also becomes finer grained and the bottom structures become less distinctive with flute casts becoming less abundant as ripples become more common in and on the tops of beds.

The Schenectady is estimated to be approximately 600 meters thick (Cushing and Ruedemann 1914) and is disconformably overlain by Silurian and Devonian strata.

The Frankfort Formation conformably also overlies the Canajoharie

Figure 3.2 Austin Glen type locality (Austin Glen, Catskill Creek, near Catskill, New York.

Figure 3.3 Typical outcrop of Austin Glen Formation consisting of interbedded sandstone and shale, Austin Glen, Catskill, New York.

Shale and is in Riva's C. Spiniferus to C. Pygmaeus graptolite zones. The formation consists of thin beds (5-10 cm.) of fine to medium grained greywacke interbedded with black shale (fig 3.4). Generally it is buff colored on the weathered surface with cross laminations and ripples being commonly seen. An occasional flute cast and groove cast are the main bottom structures seen in these rocks. The bed thickness and grain size show a slight increase upward in the overall section.

The Frankfort Formation is unconformably overlain by the Silurian Oneida Conglomerate in places where the conformable Ordovician Pulaski sandstone is missing (Fisher 1977). The thickness of this unit is estimated by Rickard and Zenger (1964) to be 152-244 meters thick with the variation in thickness due to the unconformity with the Oneida Conglomerate.

Quassaic

The Quassaic Formation consists of thick bedded sandstones with minor shales. The sandstones are generally massively bedded with some cross lamination in places (fig 3.5). The laminations are seen locally to be channeled on a scale of a few centimeters. Ripple marks with amplitudes of approximately 5 cm. can occur locally. The grain size is coarse with pebble conglomerate beds occurring in the middle of the formation (fig 3.6 and 3.7). This formation has recently been described in detail by Waines (1983) and with minor modifications, his description is as follows.

Unit 1

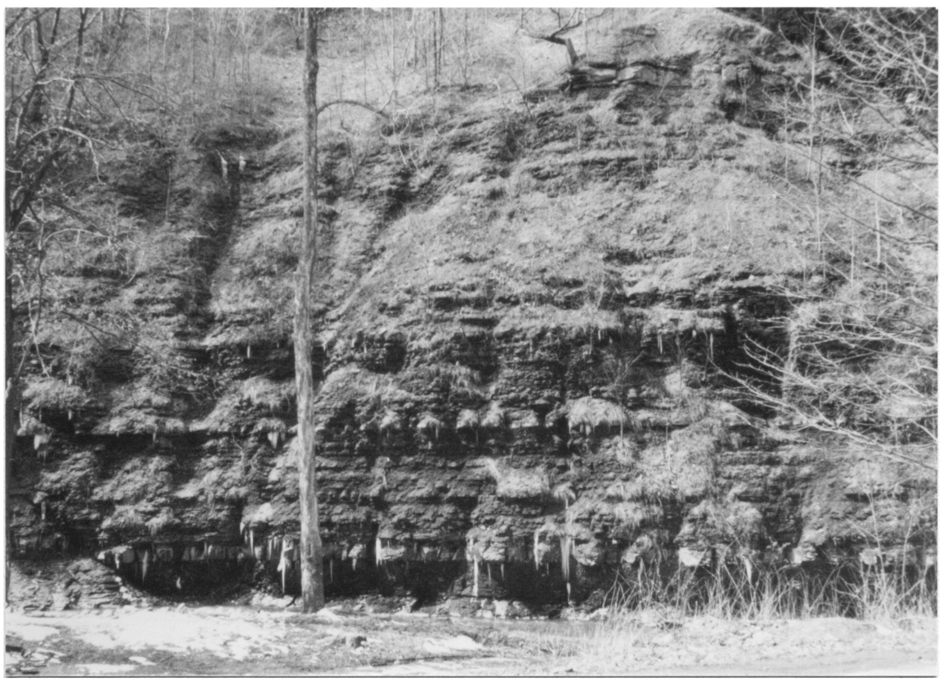


Figure 3.4 Outcrop of Frankfort Formation consisting of thin bedded sandstone and fissile black shale, Frankfort Gorge near Utica, New York.

Figure 3.5 Massively bedded sandstones of Quassaic Formation located on Route 299 east of New Paltz.

Figure 3.6 and Figure 3.7 Conglomerate beds of Quassaic Formation consisting of carbonate clasts in quartz rich sandstones.

400 meters thick. Alternating thick bedded sandstones and shales with the percentage of shale diminishing to the north and south.

Unit 2

800 meters thick. Thick bedded sandstones with shales, conglomerates with black and green chert clasts, black and grey shales, and sandstones with white carbonate clasts.

Unit 3

700 meters thick. Thick bedded sandstones, conglomerates with rare to abundant red chert and red shale clasts along with black and green chert clasts, black and grey shales, and sandstones with white carbonate clasts.

Unit 4

700 meters thick. Thick bedded sandstones and carbonate conglomerates.

Unit 5

600 meters thick. Thick bedded sandstones minor interbedded shales, minor conglomerates with black and green chert clasts, black and grey shales, and sandstones with white carbonate clasts.

Fossils are rare in this formation but a few finds of graptolites place this formation from late medial to medial Late Ordovician in age (Waines 1984).

CHAPTER FOUR.

FACIES

Facies as defined by De Raaf et al. 1965 (Blatt, Middleton and Murray 1980) is a group of rocks which are distinguished by "lithological, structural and organic aspects detectable in the field". The study of the facies of a group of rocks leads to knowledge of the depositional environment which in turn helps with the eventual reconstruction of tectonic events at the time of deposition. The term facies as defined above can be used in several different ways: 1) in a strictly descriptive sense, e.g. a sandstone and shale facies 2) in a genetic sense, e.g. turbidite facies 3) in an environmental sense, e.g. deep water marine facies 4) in a tectonic sense, e.g. molasse. In discussing the area I studied facies will be used in each of these ways.

Turbidity Current

The appearance of clastic sandstones in conjunction with deepwater marine shales was a paradox until the turbidity current hypothesis for emplacement of the sandstones was proposed (Kuenen 1953). My interest in turbidity currents lies in comparing the sedimentological features seen in a turbidite with those found in the Ordovician sandstones of New York State.

The turbidity current idea has a long history behind it (see Dzulynski 1965 and Reading 1978 for excellent discussions). The classic modern work on turbidity currents were the flume experiments by Kuenen and Migliorini (1950) where they defined a turbidity current as a high density suspension of sand and mud. In these flume experiments they were able to reproduce, by depositing material from a turbidity current, many of the sedimentary features found in deep water sandstones. After this work the turbidity current hypothesis became an accepted process for the deposit of deep sea sands.

The flow of a turbidite is due to the excess density given to it by a suspended sediment load. The sediment load is held in suspension by the internal turbulent flow of the fluid, the turbulence being maintained in part by the friction between the fluid and the surface over which it is passing and in part by the internal friction of the fluid during flow. A slope is needed in order that the energy loss due to friction is replaced by the kinetic energy gained from gravitational potential energy on traveling down the slope . As the slope flattens the current slows and sediment starts to be deposited. The current continues to decelerate until eventually all the sediment comes out of suspension and the current ceases to exist.

Turbidite

The product of a turbidity current is called a turbidite (Kuenen 1957). The "classical turbidite" deposit has been found to have distinctive sedimentary structures by which it can be recognized. These structures can be divided into two general categories; sole marks caused by current action on the underlying surface and bedding features, which form during the deposition of the sediment. In addition these sedimentary features are also useful for determining the younging direction of the strata and paleocurrent direction.

Sole Marks

Sole marks are those surficial irregularities of sedimentary origin found on the bottoms of sandstone beds (Kuenen 1957). They are created when the flow of the turbidity current is strongest and are generally the casts of depressions or markings originally produced in the mud layer over which the turbidite was deposited.

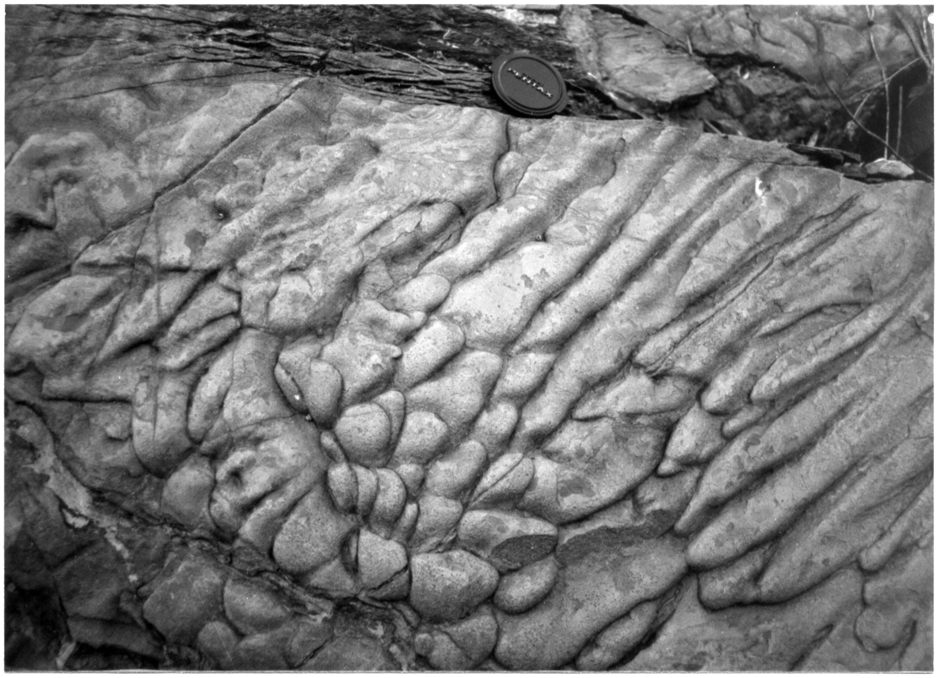
These features are of two types: scour marks, formed by the current eroding or deforming the underlying mud, and tool marks, formed when an object being carried by the turbidity current is dragged and/or bounced along the underlying bed. Dzulynski and Walton (1965) and Pettijohn and Potter (1964) discuss these features and present excellent photographs of the common sedimentary features seen in turbidites.

Features commonly found in the Pawlet, Austin Glen, Schenectady and Frankfort Formations include flute casts, load casts, ripple marks and groove casts.

Flute Casts

Flute casts (Crowell 1955) are elongate structures which have a bulbous upcurrent end and a down current end which flares and merges with the bedding plane. They vary in length from a few centimeters to a few 10's of centimeters or larger (fig 4.1 and 4.2).

Flute casts are created by the scouring effects of localized eddies eroding the underlying mud with the depression eventually becoming



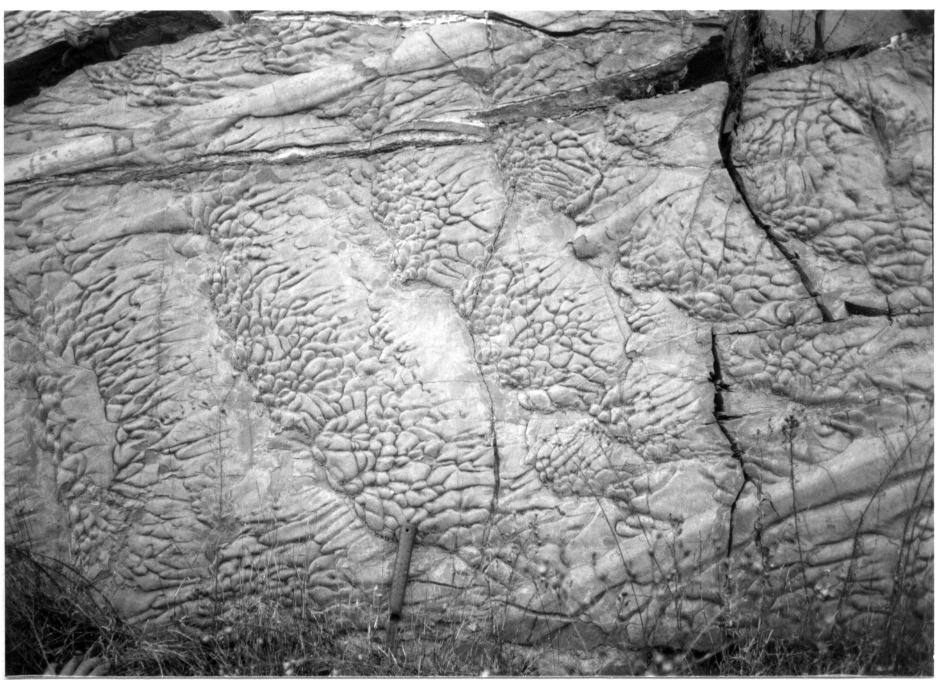


Figure 4.1 and Figure 4.2 Flute casts found in Austin Glen Formation, Route 9W, south of Hannacroix, New Baltimore, New York.

filled with sand. Flute casts generally occur in groups, are most commonly seen in the thicker beds and are very useful as unidirectional paleocurrent indicators.

Load casts are bulbous masses commonly seen on the bottom of turbidite beds (fig 4.3). They are due to the uneven loading of the deposited sand into the underlying saturated mud. These are commonly seen in the Austin Glen, Pawlet and Schenectady formations while they are rare to absent in the Frankfort formation.

Ripple marks are current generated structures which are generally seen only on the thin bedded sandstones of the western part of the area studied. Ripples form from a weaker current than that which forms flute casts. The ripples are of the asymmetric cross-section type which is indicative of a unidirectional current.

Groove casts are rectilinear features found on the undersides of turbidite beds. These originate when an object being carried by the turbidity current is dragged along the underlying mud leaving a furrow which eventually is filled in (fig 4.4). These are common features seen in most of the outcrops studied and are excellent bidirectional paleocurrent indicatiors.

BEDDING FEATURES

Bouma (1962) noted a consistent association of internal sedimentary features seen in a turbidite. He divided this vertical sequence into 5 intervals (A-E) based on sedimentary structures which he attributed to changes in the flow regime (a combination of flow velocity and

Figure 4.3 Load casts from bottom of sandstone bed, Austin Glen, Catskill, New York.

Figure 4.4 Groove cast on bottom of sandstone bed, Austin Glen, Catskill, New York.

turbulence) during deposition.

It is rare, in my area of study, to find a complete Bouma sequence in an individual turbidite. Generally what is seen is a dominance by either the lower divisions (eastern part of study area) or the upper divisions (western part of the study area).

The sandstones in the eastern section of the study area have a high percentage of thick beds with graded bedding (division A) (fig 4.5) being poor to absent while this feature is much more prominent in the thinner beds of the western section. Horizontal laminations (division B) a m.m. thick or less can be traced the entire length of the exposed bed and are generally restricted to the upper few centimeters of the thick beds but on the thinner beds (<30cm) this feature can be much more extensive, as up to 3/4 of the bed may be horizontally laminated.

Cross bedding or cross laminations (division C) (fig 4.6) are usually found only in the top few centimeters of the thick beds and generally occur in conjunction with and immediately above the horizontally laminated part. The thinner beds are found in some examples to be cross-laminated throughout the entire bed.

Above the crossbedding the thicker beds pass into fine grained sediment but it is difficult to tell whether it belongs to the turbidite (division E) or if it is pelitic sediment. The cross bedding in the thinner turbidite beds may pass up into a horizontal lamination (division D) which is similar to the one found below the cross bedding only in finer grained material. This lamination passes up into still finer grained material which again is difficult to classify as of turbidite or pelagic origin.

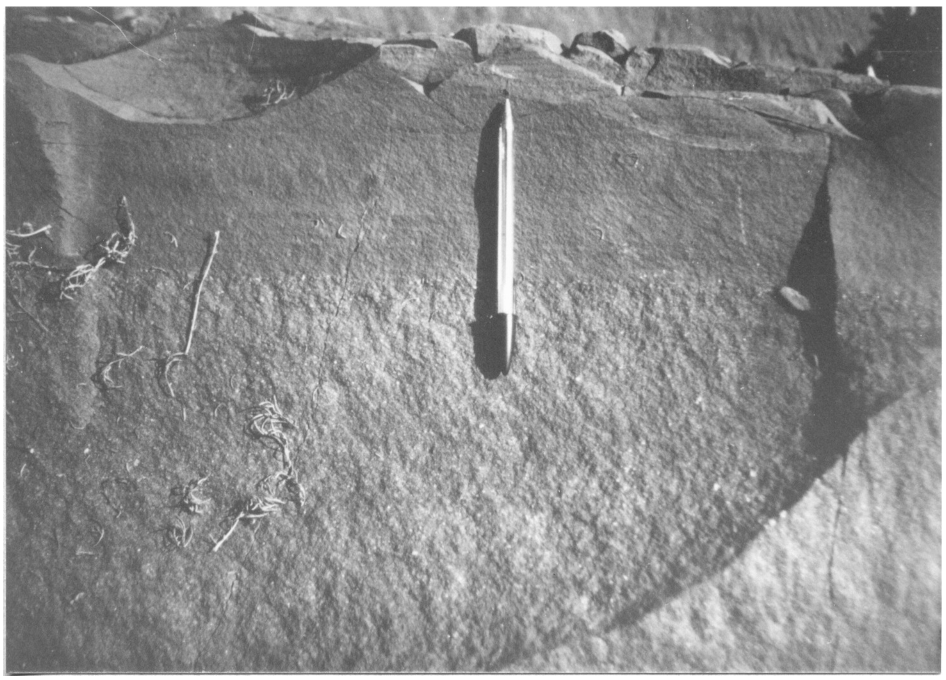


Figure 4.5 Graded bedding in sandstone bed of Schenectady/Frankfort Formation (point of pen indicates younging direction).

Figure 4.6 Crossbedding seen in top of sandstone bed.

Walker (1967) compiled criteria for distinguishing whether a turbidite is proximal or distal. Proximal turbidites are seen to have thick beds which are, on a large scale, irregular in thickness with the frequent amalgamation of beds. Internally they are coarse grained with graded bedding either absent or poorly developed, and high flow regime sedimentary structures such as scours are more common than laminations and ripples. These features indicating proximality are found in the Pawlet, Austin Glen and the eastern part of the Schenectady/Frankfort. In the western Schenectady/Frankfort features indicating the more distal nature of these deposits are found. These features include parallel sided thin beds which rarely amalgamate, fine grained beds which are well graded. Low flow regime structures such as ripples and laminations are more prevalent than scours.

Flysch Facies

Flysch is a term which was initially used by Studer in 1827 (Dzulynski 1965) to describe a distinct sequence of clastic rocks found in the Alps. Over the years use of this term has evoked much controversy and confusion among geologists (For a thorough discussion of the evolution of its use see Hsu 1970). At present time flysch is accepted as a facies term (Reading 1978) which Friedman (1978) (slightly modified) defines as

´A suite of marine sedimentary strata consisting of monotonously interbedded alternating layers of laterally persistent sands and/or coarser sediments and shales that form thick sequences which are associated with orogenic belts.´

The deposits found of the Pawlet, Austin Glen, Schenectady/Frankfort formations conform to the description of the flysch facies (and they also happen, like the type flysch, to have been deposited in a deep water environment associated with an orogenic belt).

Shallow Water Sandstones

The sedimentary features of the Quassaic are very dissimilar to those found in the other formations in this study. No evidence is seen for either turbiditic or deep water origin for these sandstones. These are coarse grained, quartz rich sediments with conglomerates and minor shales. The beds are massive with cross lamination being the only common sedimentary structure seen (fig 4.7 and 4.8). These laminations show indications of being reworked by channelling and by ripples which are up to 5 cm. in amplitude.

Bird and Dewey (1970) classified these sediments as belonging to the molasse facies. The use of the term molasse is varied and confusing, but in general it is thought to be a thick sequence of sandstones and conglomerates from a source area undergoing rapid uplift and erosion (Miall 1978). Molasse is usually considered to be a late to post orogenic intermontane or foreland deposit.

Describing the Quassaic formation as being molasse facies seems appropriate but a more extensive examination of the depositional features and the relationship between the Quassaic and the formations underlying it are needed to resolve the true nature of this unit.

SUMMARY

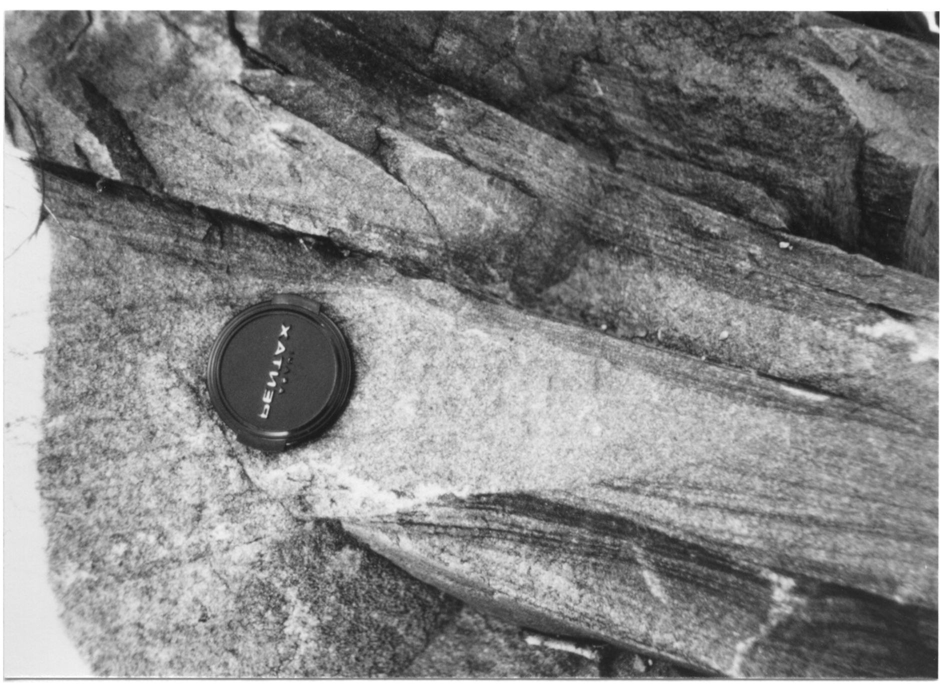


Figure 4.7 and Figure 4.8   Crosslaminations seen in massive sandstones of the Quassaic Formation.

The medial Ordovician sedimentary units of New York State are found to be of two different facies both of which are related to a mountain building environment. The oldest sandstones are deep water sediments deposited by turbidity currents and found interbedded with shale (flysch). The depositional environment of the flysch grows more distal from east to west.

The Quassaic formation is proposed to be of molasse facies and is deposited in an undetermined shallow water envirionment. This is presumed to be a late to post orogenic deposit which succeded earlier flysch deposition.

CHAPTER FIVE

PETROGRAPHY

The composition and texture of 237 thin sections was studied with the intention of determining the source of the detritus contained within them. Modal percentages of the major components were estimated by counting 300-500 points per slide. Textural features studied include grain size, estimate of degree of sphericity and angularity and grain to grain relationships.

General Appearance

Based on the detrital mineralogy and textural features two distinct types of sandstones are found to exist. The sandstones found in the turbiditic deposits of the flysch (Pawlet, Austin Glen, Schenectady/Frankfort) are poorly sorted, immature, lithic wackes (fig 5.1) (Dott 1964, Pettijohn et al 1972), while the samples from the Quassaic Formation are lithic to quartz arenites (fig 5.2).

The turbiditic sediments consist of quartz and lithic fragments supported in a matrix of fine grained clay and mica which has been chloritized. In places the matrix can be seen to be replaced by carbonate cement. A detailed study was not made of roundness but the grains from both the turbidites and the Quassaic Formation show a range in their degree of roundness from subangular to well rounded. This is

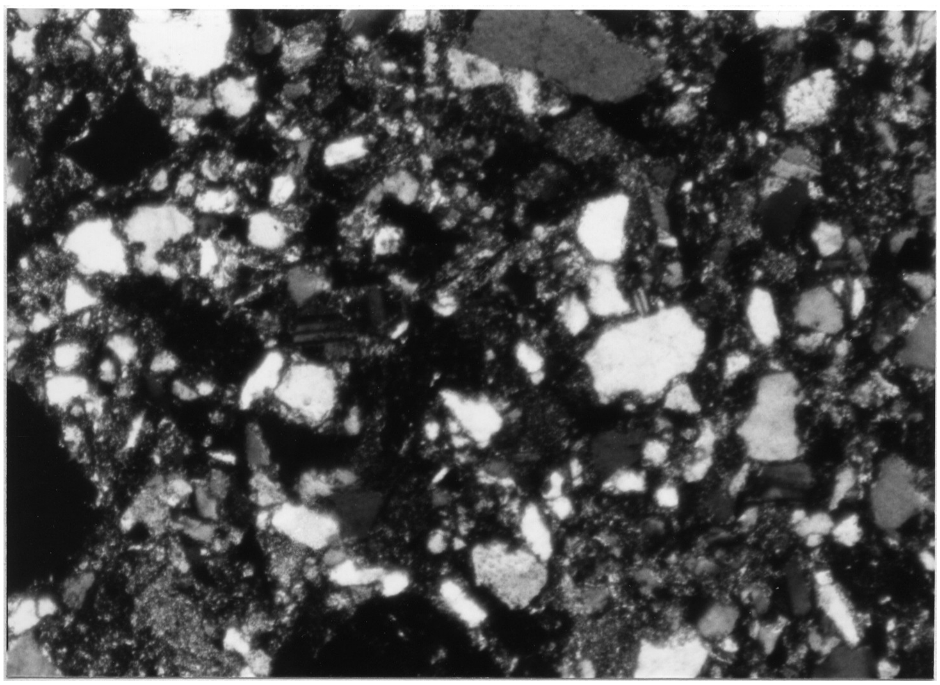


Figure 5.1 Typical texture of sandstone from flyschoid sediments (Pawlet, Austin Glen and Schenectady/Frankfort). Sample Pgh 100B (note: letters in all sample numbers refer to 7½ minute map quadrangles – see plate 1 for sample locations). Picture shows area approx. 3mm across horizontal dimension.

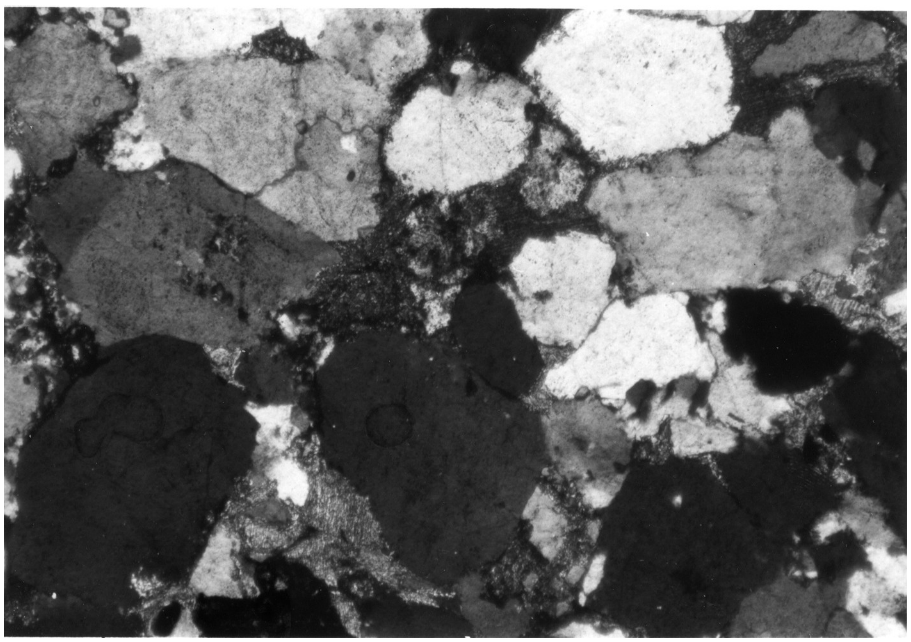


Figure 5.2 Typical texture of sandstone from Quassaic Formation. Sample Pgh 107D. Picture shows area approx. 3mm across horizontal dimension.

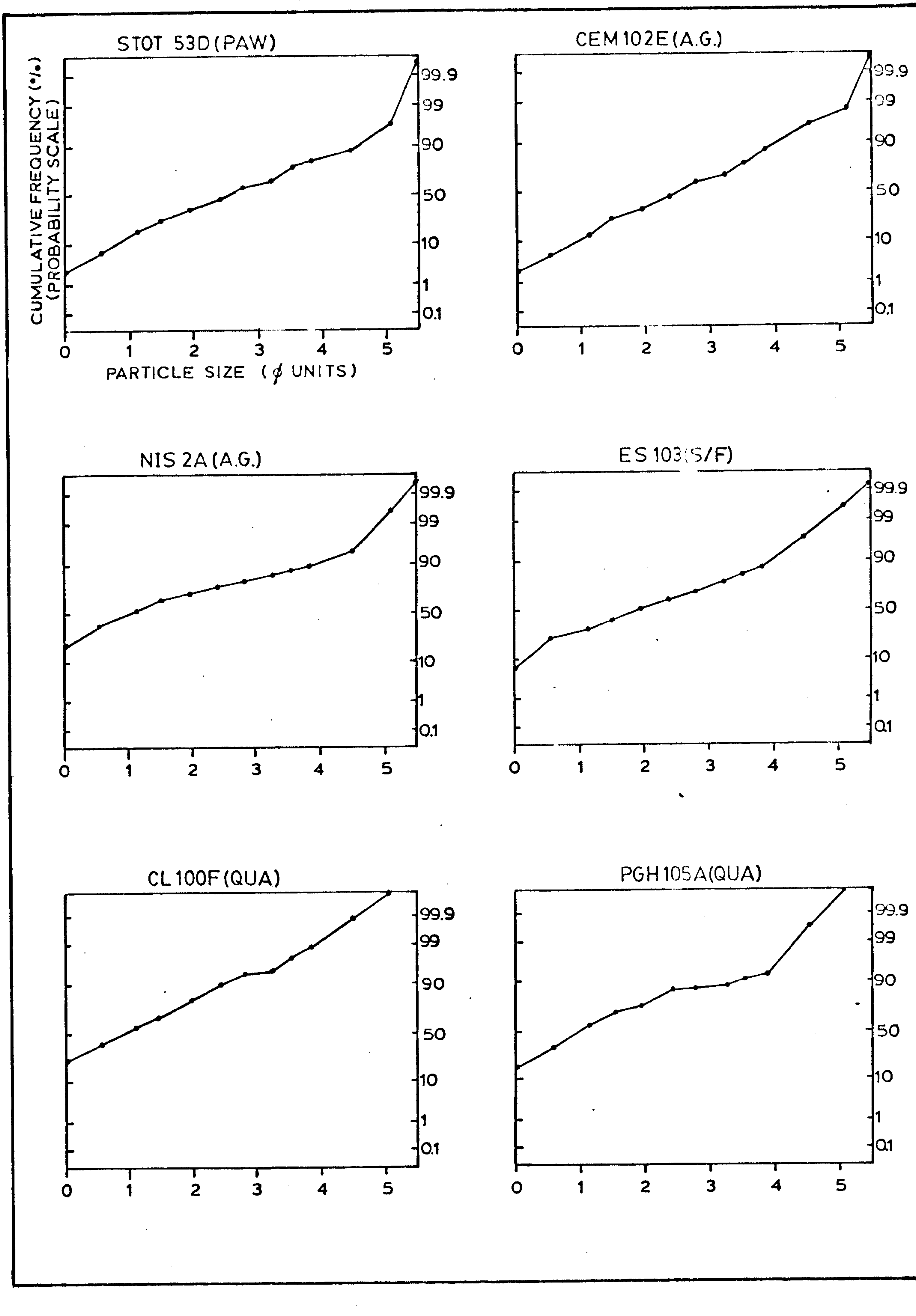
indicative of different transport histories, and for the well rounded quartz grains, either a long transport history or, more likely, a multicycled depositional history for the grains to have been abraded to the extent found.

The grain size ranges from fine to coarse with individual grains less than .01 mm. across being difficult to distinguish. Three hundred quartz grains from 4 different thin sections were measured and the cumulative frequency plots of the data are shown in fig 5.3. Plotting the data in this manner allows statistical parameters such as the mean, median and standard deviation to be inferred directly from the graph. Also, a normal distribution will plot as a straight line and deviations from a normal distribution will plot as individual line segments. This deviation can be attributed to the mixing of subpopulations. These subpopulations can be attributed to either differences in the mechanism of deposition or to the combining of contributions from different source areas. While this issue was not studied in detail the mixture of detritus of varying degrees of maturity found in the turbiditic deposits would seem to favor a combination of source areas causing the deviations from normal distribution shown on the plots.

Composition

The modal percentages of the major components were determined by point counting 300-500 points per thin section using a Swift Automatic Counter. Ten components were chosen for counting after examining the thin sections and determining the major components. When treating the compositional data a distinction was made between the Pawlet, Austin Glen and Schenectady/Frankfort flysch, and the Quassaic sandstones. The

Figure 5.3 Cumulative frequency plots of grain sizes (quartz grains). Sample number and formation is indicated along top of each plot.



STOT 53D (PAW)
CEM 102E (A.G.)
NIS 2A (A.G.)
ES 103 (S/F)
CL 100F (QUA)
PGH 105A (QUA)
CUMULATIVE FREQUENCY (%)
(PROBABILITY SCALE)
PARTICLE SIZE (ϕ UNITS)
0.1
1
10
50
90
99
99.9
0
1
2
3
4
5

average compositions found for each of the four units are shown in fig 5.4.

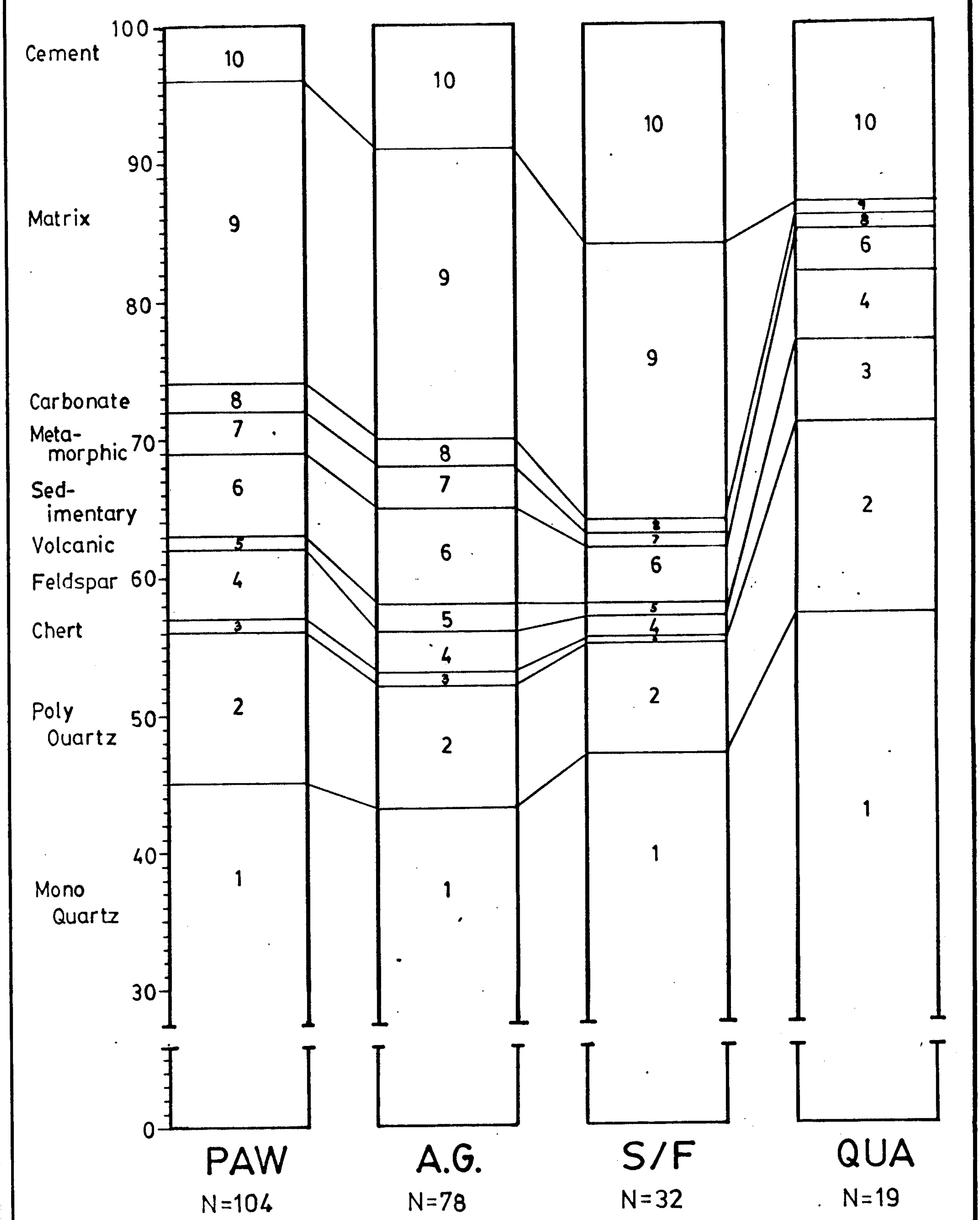
Quartz

Quartz is the most ubiquitous mineral found composing from 50 to 85% of an individual sample. The majority of the grains are .5 to .05 mm. across with a few grains being larger than 1 mm.. Both monocrystalline and polycrystalline grains are present with the former outnumbering the latter. The grains have a varying degree of roundness, subangular to rounded (fig 5.5), with angular clasts dominating. Quartz is abraded at a slow rate and the excellent degree of rounding found in certain grains indicate a long transport history and, most likely, a multicyclic origin.

A close examination of the rims of the quartz grains show them to be irregular due to replacement by authigenic calcite. In rare grains this calcite replacement product can be seen to have extensively overgrown the entire grain. Microscopic inclusions are common in the quartz but no identifiable minerals were noted. The quartz grains seen in the turbiditic sediments are matrix supported while those found in the Quassaic are grain supported and sutured contacts between individual grains can be seen.

A study by Basu et al (1975) resulted in a scheme which uses the percentages of monocrystalline and polycrystalline quartz along with the degree of undulosity in the monocrystalline grains to determine the provenance of the grains (fig 5.6). The plotting of 21 samples according to this scheme suggests a low to medium grade metamorphic

Figure 5.4 Average composition for all samples point counted (separated into formational groupings).


Cement
Matrix
Carbonate
Meta-morphic
Sed-imentary
Volcanic
Feldspar
Chert
Poly Quartz
Mono Quartz
100
90
80
70
60
50
40
30
0
10
9
8
7
6
5
4
3
2
1
PAW
N=104
A.G.
N=78
S/F
N=32
QUA
N=19

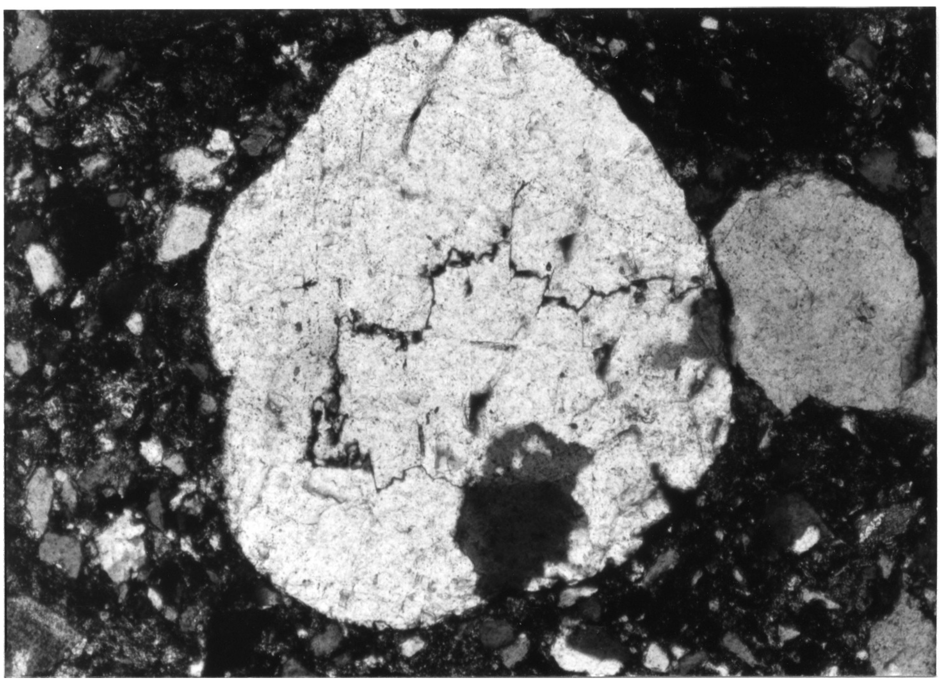
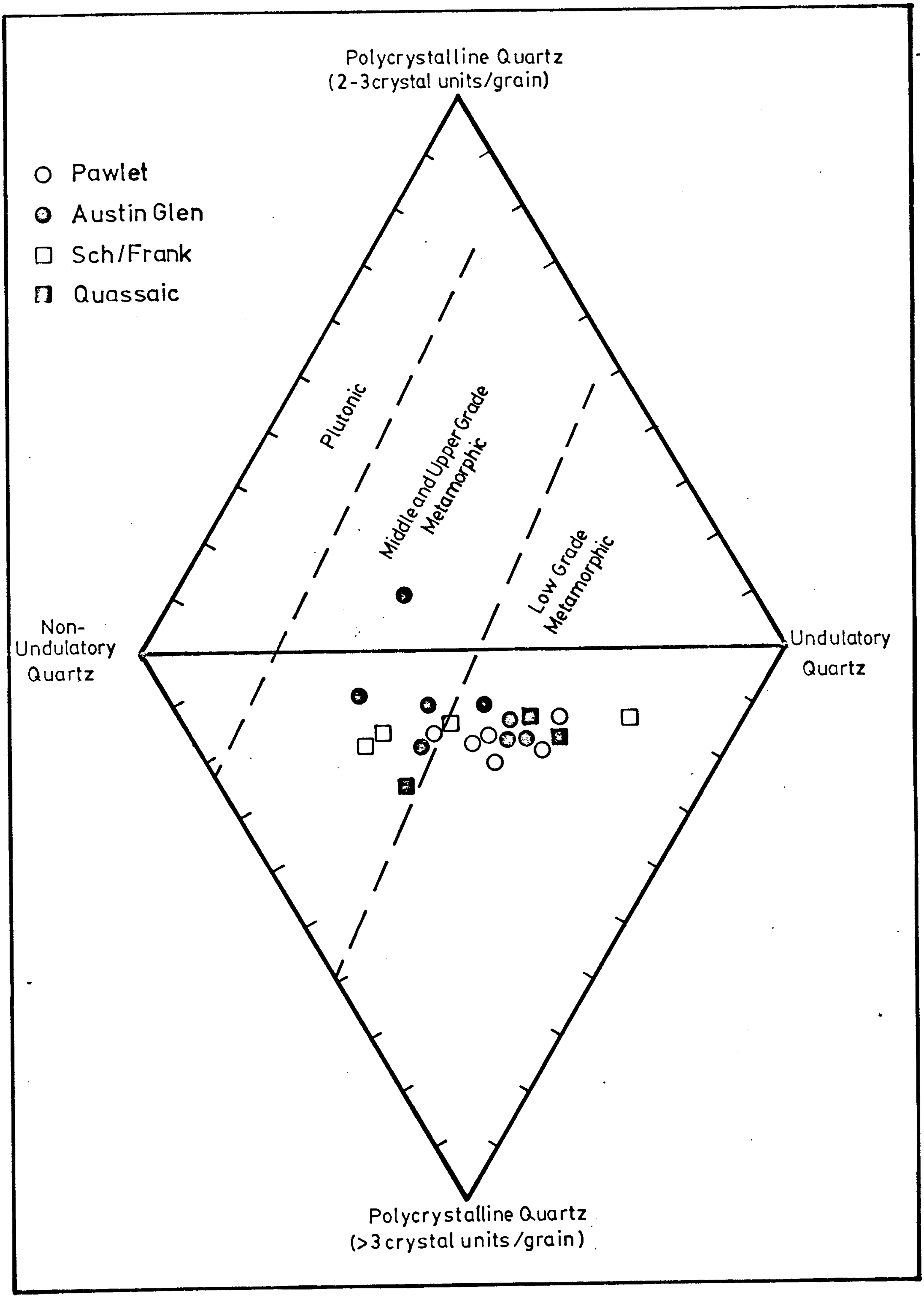


Figure 5.5 Well rounded quartz grain found in Pawlet Formation. Sample Stot 54A. Picture shows area approx. 3mm across horizontal dimension.

Figure 5.6 Quartz type and undulosity plot showing possible source of quartz detritus found in samples.


Polycrystalline Quartz
(2-3crystal units/grain)
O Pawlet
Austin Glen
Sch/Frank
Quassaic
Plutonic
Middle and Upper Grade
Metamorphic
Low Grade
Metamorphic
Non-
Undulatory
Quartz
Undulatory
Quartz
Polycrystalline Quartz
(>3 crystal units/grain)

origin for the quartz of these samples.

Chert

The chert grains are generally well rounded and occur in significant amounts only in the Quassaic. The chert appears in two different forms, as clasts where the individual silt sized grains can be distinguished and as a dark cryptocrystalline mass. The first type is seen commonly in all the samples while the cryptocrystalline grains occur only in the Quassaic. The chert clasts are abundant in the Quassaic conglomerate and show varying degrees of oxidation which manifests itself in a reddish coloration imparted on the grains. Grains can be entirely red or entirely grey while others show alteration to grey with only a core of red remaining.

Feldspar

Up to 6% modal feldspar is found in these samples. Most grains are fragmented and rounded but a few euhedral grains of plagioclase or microcline can be found in the Quassaic. The feldspar is generally .1 mm. or less in size but grains of microcline range up to .4 mm. across.

Six thin sections were stained for plagioclase (Amareth) and potassium feldspar (Sodium Cobaltinitrate) to determine the ratio of it with plagioclase. The results are presented in fig 5.7. The data indicate that the microcline content increases in the younger flysch and in the Quassaic samples.

Calcite replacement of feldspar can be seen to have taken place to varying degrees, with the plagioclase generally being more altered than

SAMPLES STAINED FOR
PLAGIOCLASE AND POTASSIUM FELDSPAR

LOCATION	SAMPLE	% PLAG.	% K-SPAR	% PLAG/% K-SPAR
Pawlet	Gr 3	92%	8%	11.5
Austin Glen	HN 100K	87%	13%	6.7
Sch/Frank	Alt 2A	75%	25%	3.0
Sch/Frank	Es 101	63%	37%	1.7
Quassaic	Pgh 103B	30%	70%	.4
Quassaic	Pgh 104B	30%	70%	.4

Figure 5.7

the microcline. In some instances the complete replacement of a plagioclase grain has taken place, with only the psuedomorphic outline remaining to identify it. Plagioclase (fig 5.8) and microcline are found both twinned and untwinned with the latter having the most untwinned grains.

Sedimentary Clasts

Sedimentary rock clasts comprise 4-6% of most samples. These clasts are generally subrounded to rounded and range up to .4 mm. in size. Clasts of shale, sandstone, greywacke and siltstone are all found (fig 5.9 and 5.10).

Shale clasts are the most common sedimentary fragment. They are medium to dark brown with a texture of randomly oriented fine grains in which individual grains are barely discernable. In the deformed Pawlet and Austin Glen the shale fragments are crushed and deformed by surrounding quartz grains.

Sandstone fragments are the next most abundant sedimentary clast. The largest fragments are approximately .3 mm. across and composed of fine grained quartz with a small amount of plagioclase (a few %) and an occasional grain of muscovite or biotite in them. The grains show sutured contacts with chlorite filling the interstitial areas.

Greywacke clasts are rare but are more commonly found in the Quassaic samples. These clasts are comprised of mainly quartz grains with minor feldspar in a dark matrix. The ones in the turbidites are usually <.5 mm. across, while in the Quassaic they range up to 1.5 mm.. One particular greywacke clast in the Quassaic bears a strong

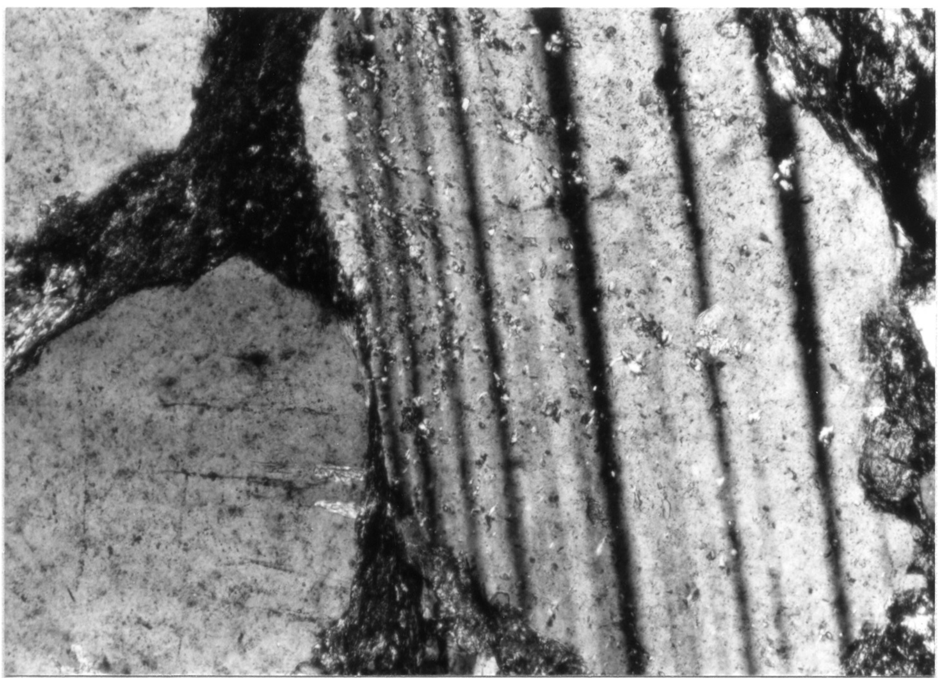


Figure 5.8 Subhedral plagioclase grain found in the Quassaic Formation. Sample Cl 100J. Picture shows area approx. 1.2mm across horizontal dimension.

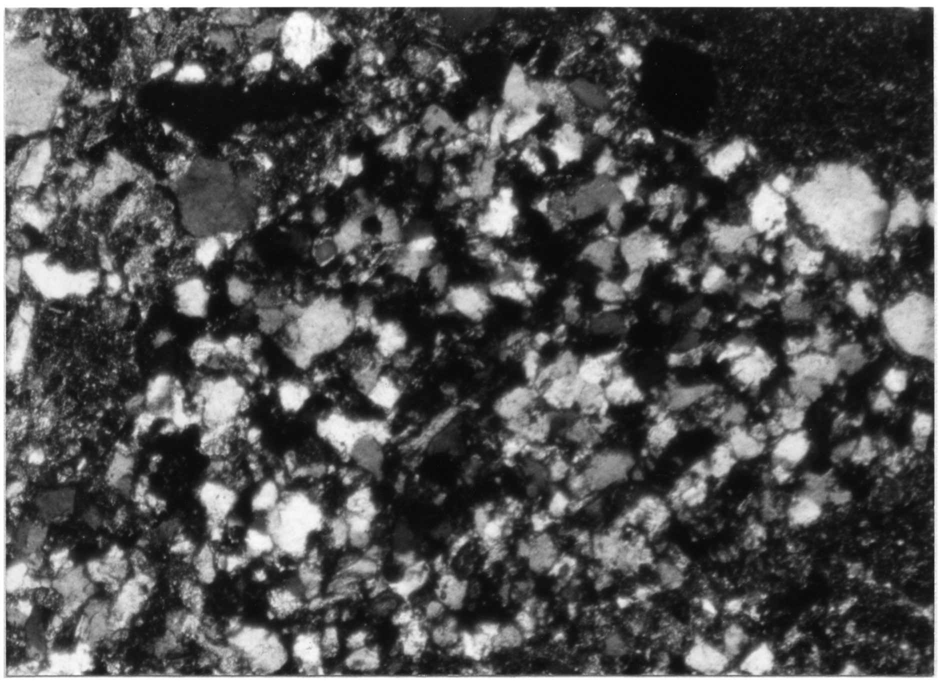


Figure 5.9 Coarse grained sedimentary clast consisting of quartz and feldspar found in the Pawlet Formation. Sample Stot 54A. Picture shows area approx. 3.1mm across horizontal dimension.

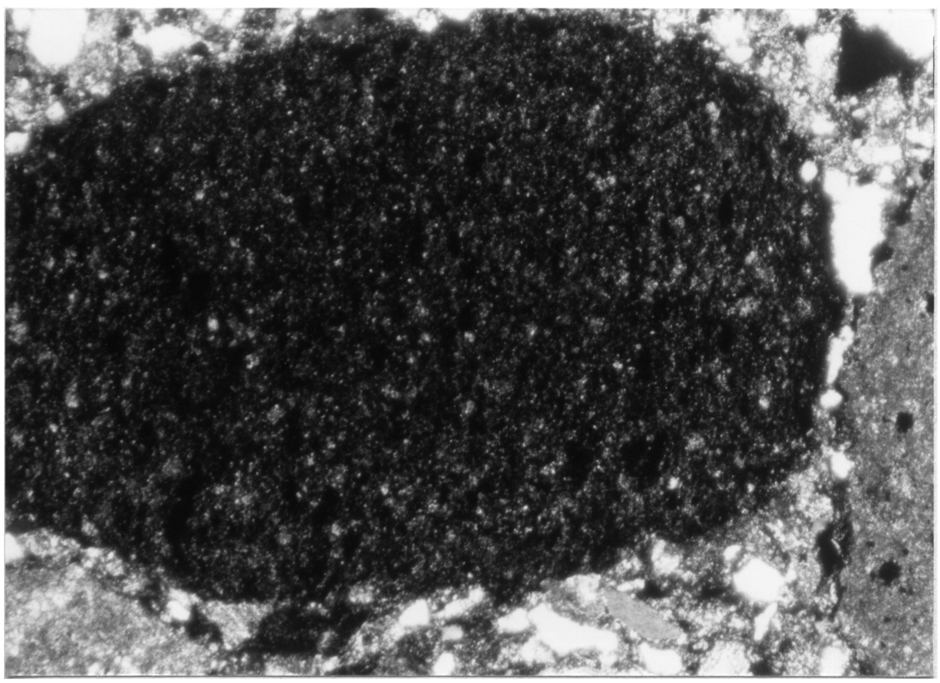


Figure 5.10 Fine grained sedimentary clast found in the Pawlet Formation. Sample Stot 54A. Picture shows area approx. 3.1mm across horizontal dimension.

resemblance to the Frankfort flysch samples.

Silt clasts are seen only in the Quassaic. These consist of angular quartz fragments imbedded in a brownish matrix (fig 5.11). Silt fragments disaggregate easily and indicate a brief transportation history according to Scholle (1979).

Metamorphic Clasts

Three types of metamorphic fragments are commonly found: low grade phyllites, slates, and quartz-muscovite schists. The phyllites are fine grained with a fabric formed by the parallel alignment of micaceous minerals (fig 5.12). They are elongate clasts with the long dimension approximately .2-.4 mm..

Quartz-muscovite schist fragments are rare. When found they are coarser grained than the phyllites, with individual grains of quartz and muscovite distinguishable. These fragments range in size from .3-.5 mm..

Slate clasts are dark brown to black with some silt sized quartz grains being the only distinguishable minerals (fig 5.13). The cleavage is defined by concentrations of fine grained dark minerals separating areas of lighter colored slightly coarser grains.

The percentage of metamorphic grains is higher in the turbiditic sediments than in the Quassaic. Phyllite and schist clasts are common in all but the finest turbiditic sediments. They are also both found in the Quassaic but the slate fragments are only found in the Quassaic, and are absent from the rest of the samples.

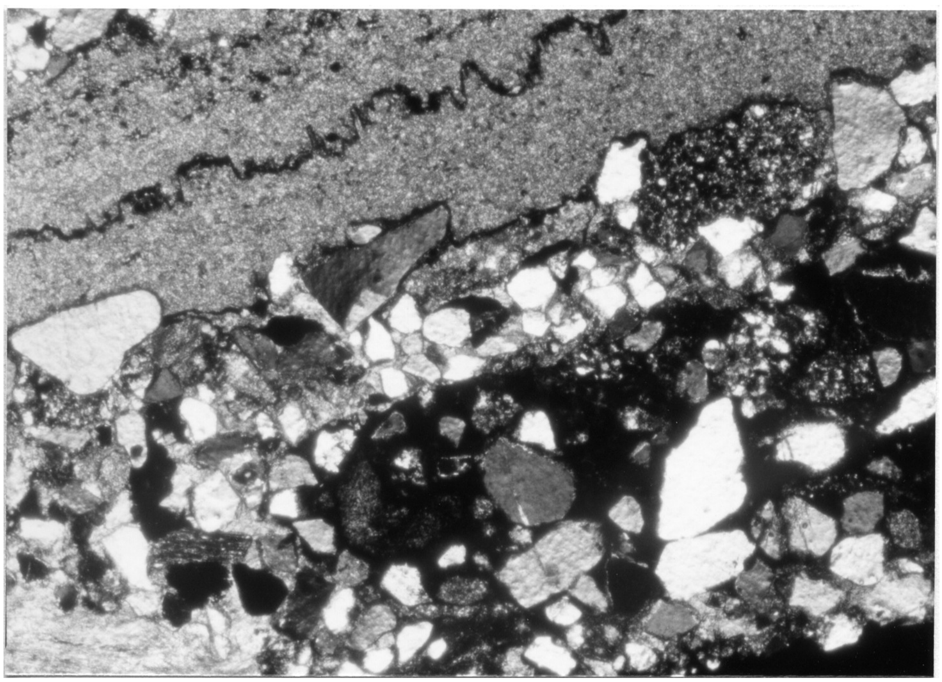


Figure 5.11 Silt clast (bottom center) in Quassaic sandstone. Sample Pgh 107A. Picture shows area approx. 4.5mm across horizontal dimension.

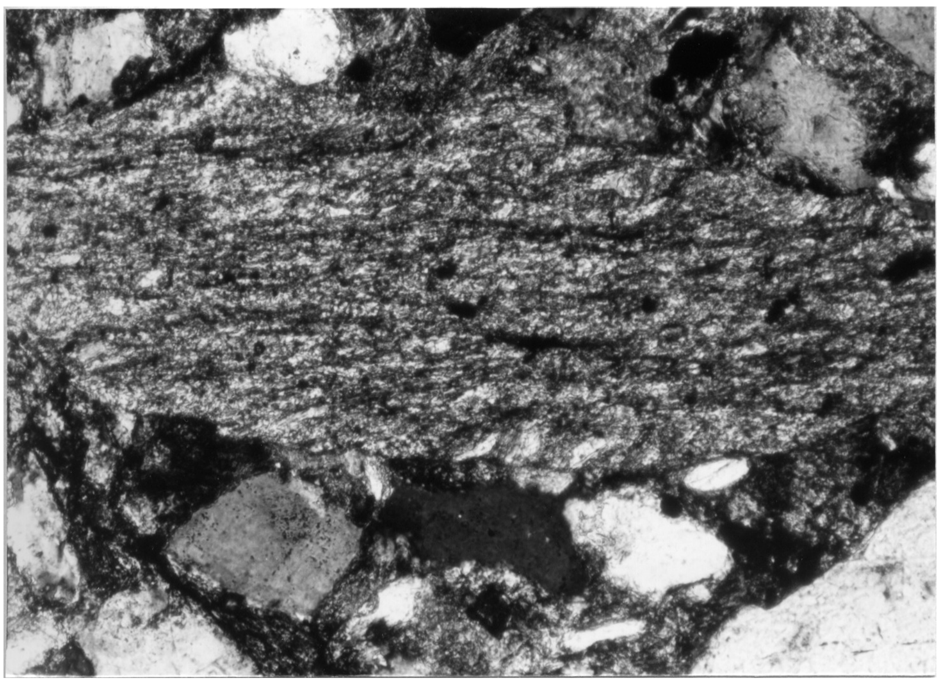


Figure 5.12 Phyllite clast in Austin Glen. Sample Cem 3G. Picture shows area approx. 1.2mm across horizontal dimension.

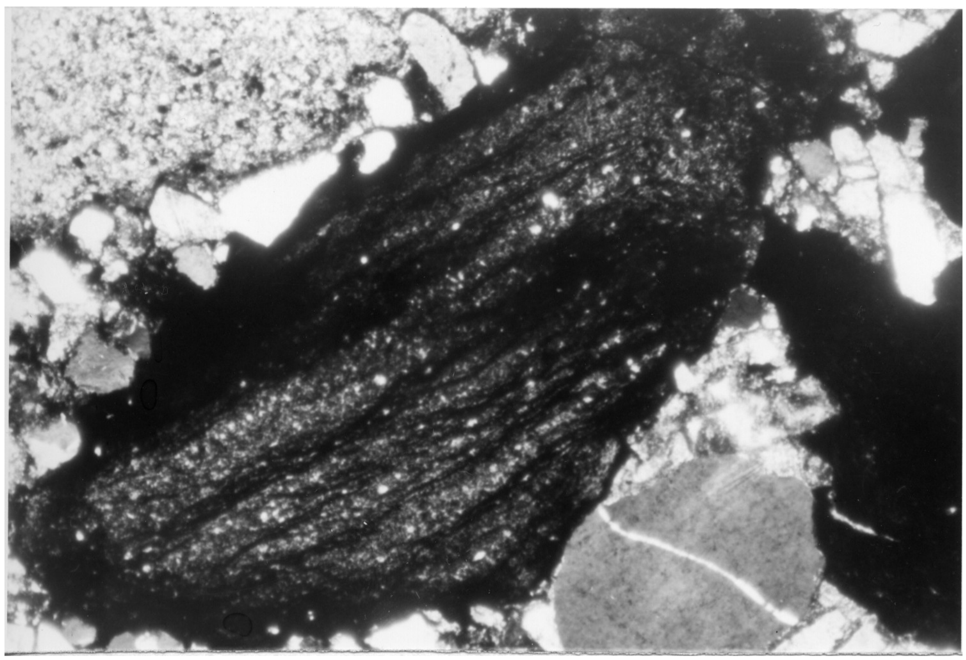


Figure 5.13 Slate clast showing cleavage found in Quassaic sandstone. Sample Pgh 107F. Picture shows area approx. 4.5mm across horizontal dimension.

Volcanics and Volcaniclastics

Volcanic clasts compose a small percentage of any individual sample (1-2%) but are important in determining the tectonic environment of an area. The composition of clasts found ranges from mafic to silicic.

The most common type of fragment consists of laths of twinned plagioclase with dark areas between the laths probably containing altered mafic minerals (fig 5.14). These fragments are well rounded, moderately spherical, and range in size from .5-2.5 mm..

The second most abundant is a silicic to intermediate volcanic rock comprised of coarse grained twinned and untwinned plagioclase and coarse grained quartz (fig 5.15 and 5.16). Between the large grains are localized areas of dark altered material. These clasts are rounded, fairly spherical and approximately 1.0-1.5 mm. across.

Volcaniclastic fragments are rounded and elongate in shape with the long dimension from 1.5-2.5 mm. and the short dimension .75-1.0 mm.. They are composed of fine grained quartz and feldspar grains widely spaced in an dark brown matrix. One particularly good example contained large (1 mm.) volcanic fragments composed of laths of twinned and untwinned plagioclase grains (fig 5.17).

The volcanic and volcaniclastics are uniformly found throughout the turbiditic sediments but are completely absent from the Quassaic.

Carbonate Clasts

Carbonate clasts make up 1-2% of the average sample. The clasts

Figure 5.14 Mafic volcanic clast consisting of laths of plagioclase in dark matrix (Austin Glen Formation). Sample Stot 54A. Picture shows area approx. 1.2mm across horizontal dimension.

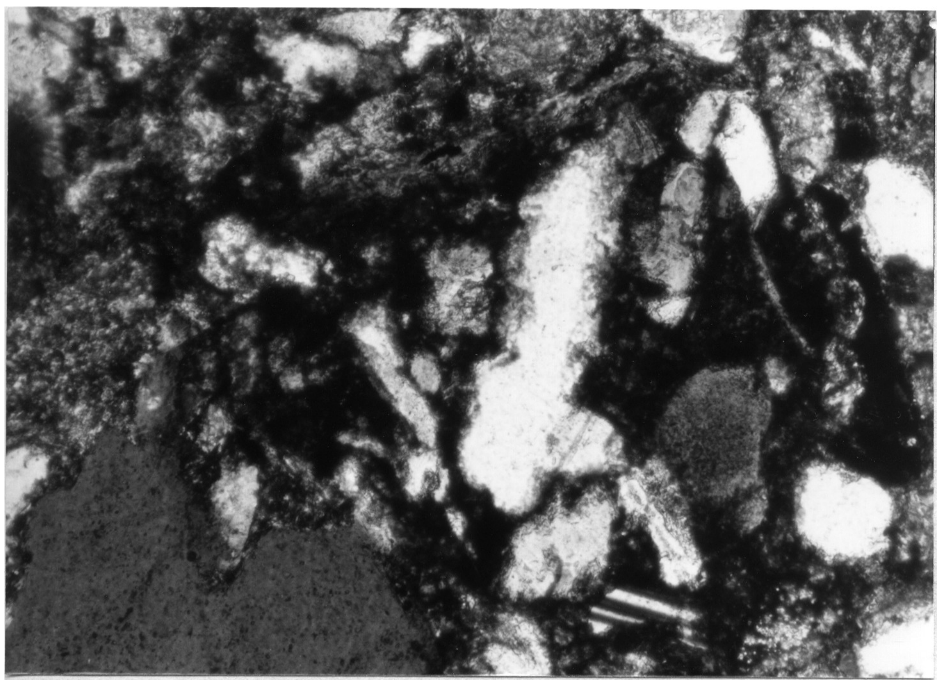


Figure 5.15 Intermediate volcanic clast consisting of quartz and feldspar in altered matrix (Austin Glen Formation). Sample Ke 100. Picture shows area approx. 1.2mm across horizontal dimension.

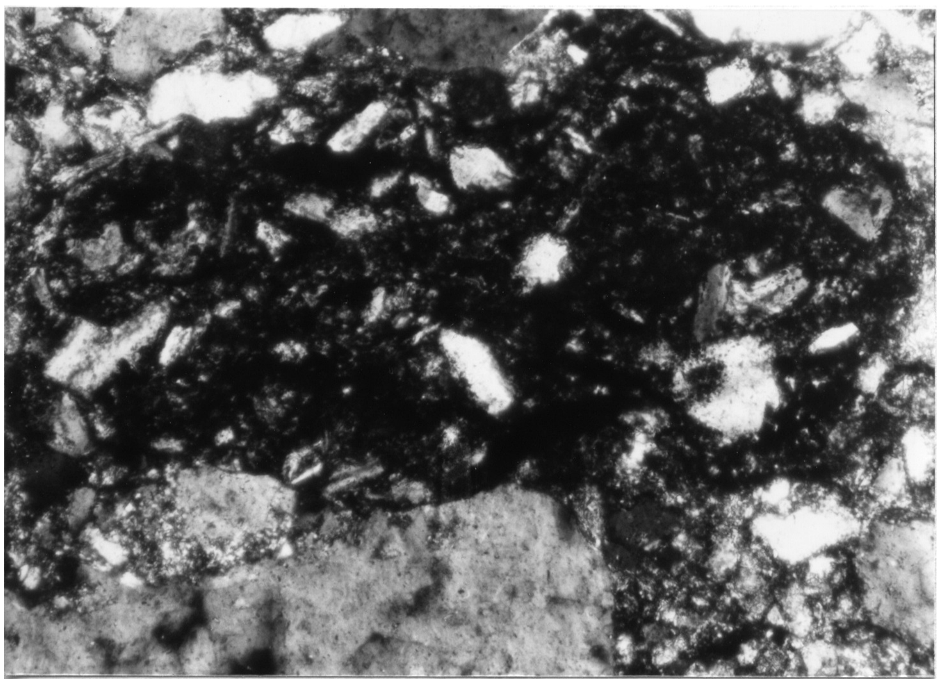


Figure 5.16 Intermediate volcanic clast consisting of quartz and feldspar in altered matrix (Austin Glen Formation). Sample Cem 3G. Picture shows area approx. 1.2mm across horizontal dimension.

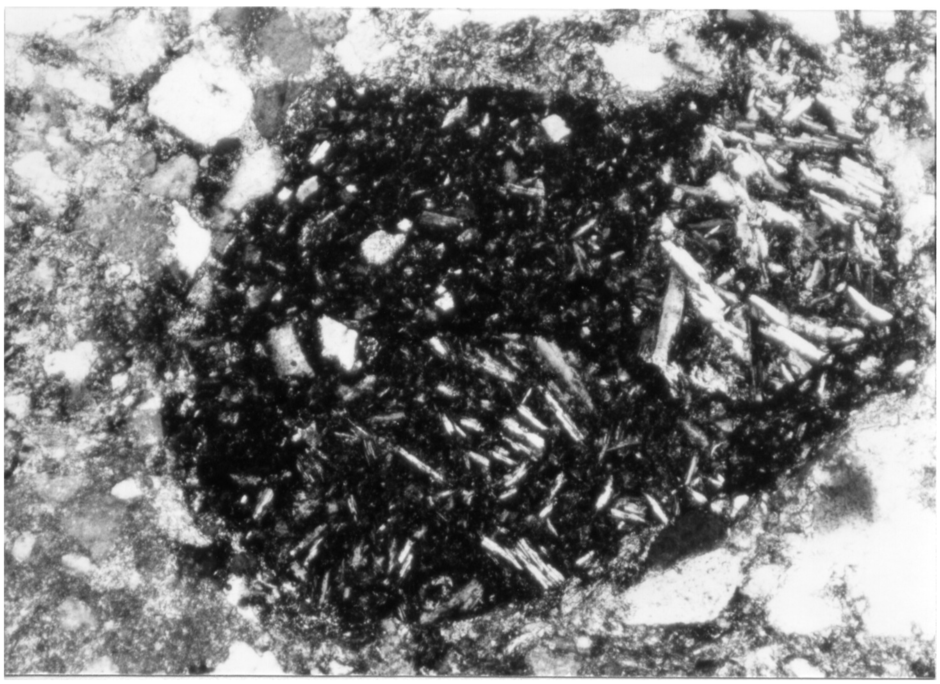


Figure 5.17 Volcaniclastic fragment found in Austin Glen. Sample Cem 3G. Picture shows area approx. 3.5mm across horizontal dimension.

are rounded and average in size from .3-.7 mm. in the turbidites and from .3-4.0 mm. in the Quassaic. The clasts are composed of either fine carbonate sand or of round carbonate pellets in a micrite matrix. The fragments have undergone varying degrees of recrystallization with a few grains consisting entirely of recrystallized calcite.

Accessory Minerals

It is not uncommon to see grains of detrital muscovite or biotite, with muscovite being the more common. In the heavily deformed sediments the muscovite is often bent or kinked.

Rounded zircon and tourmaline grains are found in most samples with zircon being the more prevalent.

Opaque heavy minerals are mainly magnetete and pyrite. Chromite has been reportedly found in small amounts in the turbiditic units (J.M. Bird in Rowley and Kidd 1981) but I was unable to confirm its presence in the samples I studied. Hiscott (1978) presented an argument that places doubt on there being an appreciable amount of detrital chromite in these samples. Hiscott found that an analysis of the heavy mineral separate from the Tourelle sandstones showed 6.8% Cr. compared with .09% Cr. found by Weber and Middleton (1961) in samples from the Austin Glen flysch. Chromite is a very stable mineral and the few grains found in samples from the area of this study could have been transported a long distance and are not necessarily from local sources.

The Quassaic Formation contains a small number of apparent plutonic rock fragments. These fragments are mainly coarse grained quartz aggregates, similar in appearance to other polycrystalline quartz fragments, with minor plagioclase or biotite. The rarity of these fragments is probably due to the source rock having mainly been disaggregated into individual mineral components.

Cement (Carbonate in matrix)

Carbonate cement is seen to some degree in virtually every sample filling the spaces between the framework grains. Two possible origins can be proposed for this cement, It either came from the dissolving of carbonate clasts contained within the samples or from an outside source such as the calcareous shales which are locally interbedded with the sandstones. Due to the paucity and small volume of carbonate clasts found in the turbiditic samples, an outside source for the cement found in these samples is more likely. The Quassaic presents a different situation because not only are large carbonate clasts seen in thin section, but in outcrop, numerous large clasts are found (up to 10 cm. in size) which could have supplied the amount of cement found in these samples.

The carbonate cement in the Quassaic fills the pore spaces between the grain boundary supported grains while the grains of the turbiditic samples are "floating" in the carbonate cement. This observation plus the fact that the cement has a dirty and chloritized appearance leads to the assumption that in the turbiditic sediments the carbonate material has to some replaced the original matrix.

Matrix

The matrix in the turbiditic samples is composed of pasty microcrystalline clay and sericite and authigenic chlorite. The percentage of matrix varies from 5-50% with an average of 19%. The origin of the matrix in greywackes has been an item of dispute for many years. There is general agreement that the matrix is composed of both detrital clay and mud along with a percentage of altered material. The disagreement arises over the origin of the altered material. Chevalier (1976) interpreted the matrix as being the alteration product of detrital clay while Cummins (1962) argued for the matrix being totally due to the diagenetic alteration of unstable feldspars and lithic framework grains. The supporters of the unstable grain origin for the matrix generally cite the fact that modern deep sea sands have little matrix (Hollister and Heezen 1964) and that Kuenen's (1966) flume experiments show only 10% of fine grained material can be expected to mix with the coarser framework grains. This source for the matrix can be disputed from two lines, the first being that DSDP cores from sites 240 and 248 (Moore 1974) show samples containing up to 20% matrix in them and the second being that the expected depletion of the unstable framework grains with an increase in matrix is not seen (Hiscott 1977).

The samples I have studied show no evidence for the matrix being produced from unstable framework grains. First, no correlation is seen to exist between the amount of matrix and the unstable lithic fragments although an increase in one should correspond with a decrease in the other. Second, the amount of variability in the percentage of matrix (5-50%) could not possibly be accounted for by the feldspar and rock fragments whose total percentage on average is only 12%.

Stratigraphic Section Comparisons

The percentages of quartz, feldspar and lithic fragments were compared in four sets of samples where they were known to have come from an intact stratigraphic succession (fig 5.18-5.21). Only the Austin Glen section was continuous, while in the others the sampling was performed using previously compiled geologic data to determine stratigraphic succession (Granville: Fillipone 1981; Esparence: Fisher 1980; Quassaic: Waines 1983). The plots have the sample numbers arranged along the x-axes from lower to higher in the sequence.

Examination of the data shows that no systematic variation in the percentages of these components occurs through the different sections. It appears the scatter found across the area is random and that the only significant change in source area is seen for the Quassaic sediments.

Figure 5.18 Plots comparing components of a continuous stratigraphic section (samples shown left to right going upward in the stratigraphy) from the Pawlet Formation near Granville, New York (approximately 500 meters of section sampled). (Sample #1-Sample Gr 1, #2-Gr 2, #3-Gr 3, #4-Gr 4, #5-Gr 5, #6-Gr 6, #7-Gr 7, #8-Gr 8)

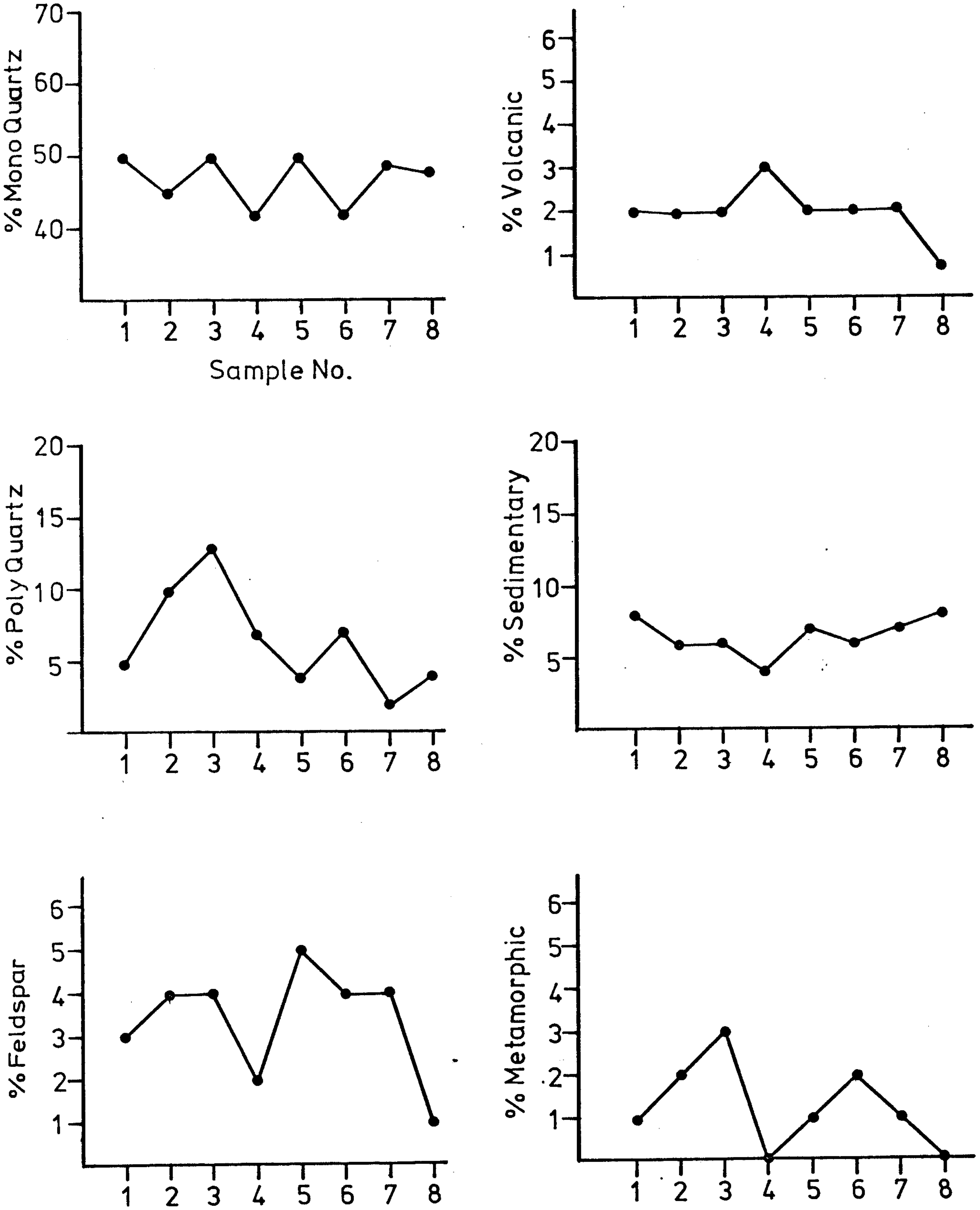
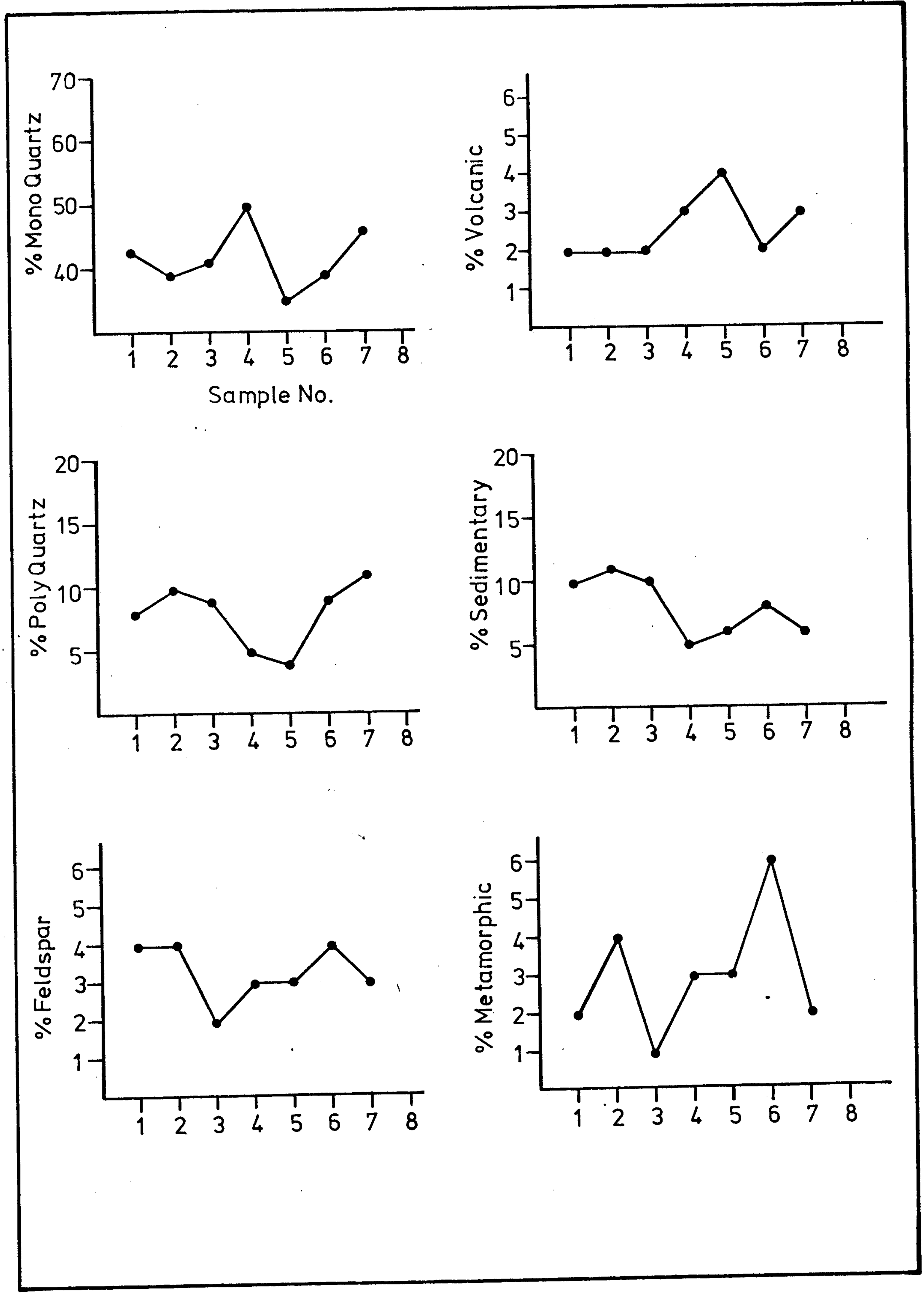

% Mono Quartz
70
60
50
40
1 2 3 4 5 6 7 8
Sample No.
% Volcanic
6
5
4
3
2
1
1 2 3 4 5 6 7 8
% Poly Quartz
20
15
10
5
1 2 3 4 5 6 7 8
% Sedimentary
20
15
10
5
1 2 3 4 5 6 7 8
% Feldspar
6
5
4
3
2
1
1 2 3 4 5 6 7 8
% Metamorphic
6
5
4
3
2
1
1 2 3 4 5 6 7 8

Figure 5.19 Plots comparing components of a continuous stratigraphic section (samples shown left to right going upward in the stratigraphy) from the Austin Glen Formation near Catskill, New York (approximately 100 meters of section sampled). (Sample #1-Sample Cem 3A , #2-Cem 3B, #3-Cem 3C, #4-Cem 3D, #5-Cem 3G, #6-Cem 3H, #7-Cem 3I)



% Mono Quartz
70
60
50
40
1 2 3 4 5 6 7 8
Sample No.
% Volcanic
6
5
4
3
2
1
1 2 3 4 5 6 7 8
% Poly Quartz
20
15
10
5
1 2 3 4 5 6 7 8
% Sedimentary
20
15
10
5
1 2 3 4 5 6 7 8
% Feldspar
6
5
4
3
2
1
1 2 3 4 5 6 7 8
% Metamorphic
6
5
4
3
2
1
1 2 3 4 5 6 7 8

Figure 5.20 Plots comparing components of a continuous stratigraphic section (samples shown left to right going upward in the stratigraphy) from the Schenectady/Frankfort Formation along the Schoharie Creek near Esperence, New York (approximately 100 meters of section sampled). (Sample #1-Sample Es 1, #2-Es 3, #3-Es 4, #4-Es 100, #5-Es 101, #6-Es 102, #7-Es 103, #8-Es 104)

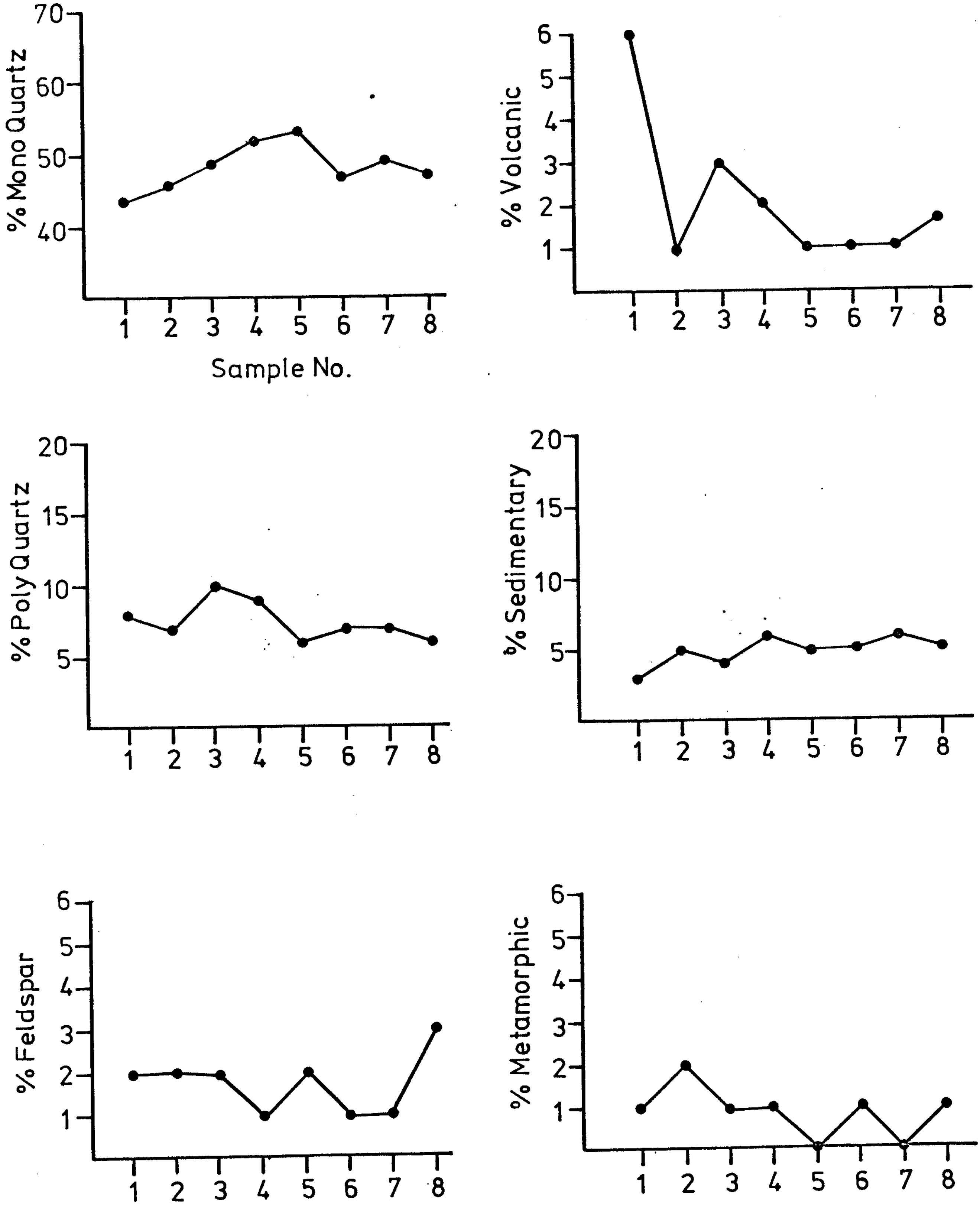
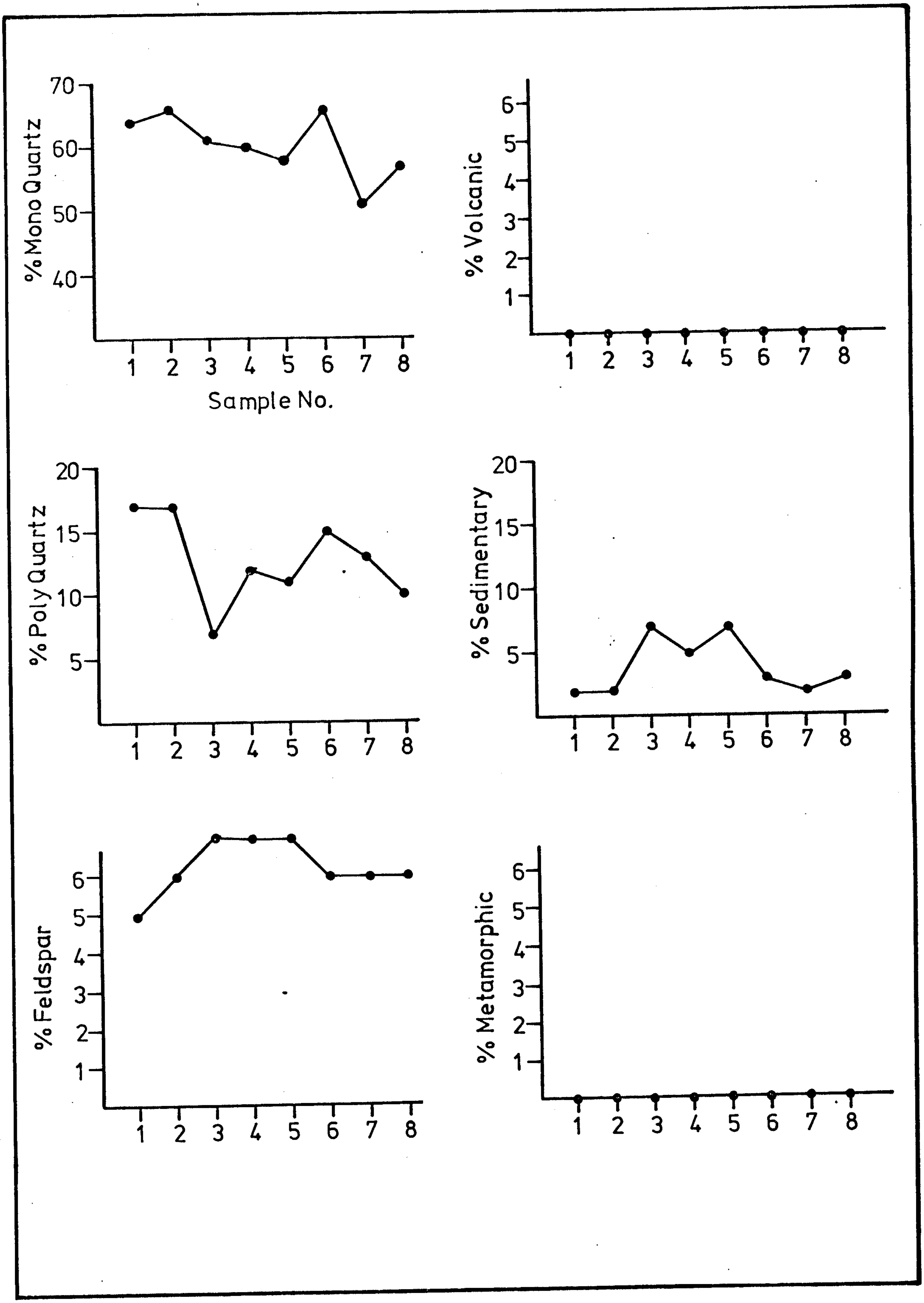

70
60
50
40
% Mono Quartz
1 2 3 4 5 6 7 8
Sample No.
6
5
4
3
2
1
% Volcanic
1 2 3 4 5 6 7 8
20
15
10
5
% Poly Quartz
1 2 3 4 5 6 7 8
20
15
10
5
% Sedimentary
1 2 3 4 5 6 7 8
6
5
4
3
2
1
% Feldspar
1 2 3 4 5 6 7 8
6
5
4
3
2
1
% Metamorphic
1 2 3 4 5 6 7 8

Figure 5.21 Plots comparing components of a continuous stratigraphic section (samples shown left to right going upward in the stratigraphy) from the Quassaic Formation between Kingston and Poughkeepsie, New York (approximately 2,100 meters of section sampled). (Sample #1-Sample Pgh 107D, #2-Pgh 102A, #3-Pgh 103B, #4-Pgh 104B, #5-Pgh 105A, #6-Kiw 1A, #7-Cl 100A, #8-Cl 100G)


% Mono Quartz
70
60
50
40
1 2 3 4 5 6 7 8
Sample No.
% Volcanic
6
5
4
3
2
1
1 2 3 4 5 6 7 8
% Poly Quartz
20
15
10
5
1 2 3 4 5 6 7 8
% Sedimentary
20
15
10
5
1 2 3 4 5 6 7 8
% Feldspar
6
5
4
3
2
1
1 2 3 4 5 6 7 8
% Metamorphic
6
5
4
3
2
1
1 2 3 4 5 6 7 8

CHAPTER SIX

PROVENANCE

The object of a provenance study is to gain insight into the regional tectonics of an area (e.g. Potter and Siever 1956, Dickinson 1971). To do this the petrography and directional structures of sedimentary rocks are studied with the purpose of finding information which reflects on source, source area location, and tectonic environment at the time of deposition.

Information on the source rocks is found through the examination of the mineral and lithic fragments along with the textural features found in thin section. The combination of material found often distinguishes the rock type or types which contributed to the makeup of the sandstone.

Structures indicating flow direction are ubiquitous in most sedimentary rocks. Measurement of these allows the paleoflow direction to be determined and, combined with the source rock information, allows inferences to be made about the paleogeography.

Studies have shown that the relative percentages of framework grains of immature sandstones can give information about the tectonic setting in which they were deposited. Data for these studies are collected from known tectonic environments by performing modal analysis on either modern deep sea sands (Valloni and Maynard 1981, Dickinson and Valloni 1980) or ancient sandstones (Dickinson 1970, 1982) and ternary plots are made whereby fields of particular tectonic settings can be defined. These ternary diagrams allow sandstones from an area being studied to be compared with those from known tectonic environments thereby assisting with regional tectonic interpretations.

SOURCE

Sedimentary Clasts

A quartz-feldspar rich sedimentary source is indicated by the sandstone, shale, feldspar and quartz found in these samples. The roundness of some quartz grains necessitates a long transport history (Kuenen 1959) and can be interpreted (e.g. Hiscott 1978) as being due to the quartz having been through more than one erosion-deposition episode. The quartz undulosity study demonstrated the quartz grains are probably from a low grade metamorphic source rather than a plutonic one. This is what would be expected from an eroded sedimentary rock. The feldspars are of two distinct textural types, one consisting of rounded and fragmented plagioclase and microcline grains which show varying degrees of alteration and the second being rather fresh looking angular grains of microcline and perthite. The first type is probably of sedimentary origin while the latter may be of plutonic origin.

The probable source for these sedimentary rock fragments is the Cambrian-Ordovician argillaceous and arenaceous sediments now exposed in the Taconic Allochthon (Zen 1967, 1968, 1972, Rowley, Kidd and Delano 1979). These sediments have been interpreted as being continental rise facies (Bird and Dewey 1970) with the oldest sediments being of rift facies.

The stratigraphy of the Giddings Brook slice of the Taconic Allochthon has been studied extensively by Jacobi (1977) and Rowley (1980) (summary in Rowley, Kidd and Delano 1979). These strata range from quartz-rich greywackes and arenites such as those in the Bomoseen and Brown's Pond Formations to argillaceous and shaly rocks such as the Truthville, Poultney, Indian River and Mount Merino. Chert is found in minor amounts in the Indian River and more extensively in the Mt. Merino. These and similar continental rise sediments were probable contributors of a large percentage of the detritus found in the sediments of this study.

An alternate source is possible for some or all of the shale clasts found. Frequently the bottoms of the greywacke beds show rip up clasts derived from the shale beds underlying the turbidite deposits (fig 6.1). This is a likely source, especially for the larger shale clasts.

Carbonate Clasts

A carbonate rock source is needed to explain the carbonate clasts in the detritus. It has not been determined whether or not the source was an active carbonate bank at the time of erosion, but in the similar Tourelle sandstones, Hiscott (1978) determined that the conodonts found in the carbonate detritus are of the same age as the graptolites contained in the interbedded shales, thereby demonstrating an active carbonate environment for these clasts.

Metamorphic Clasts

The phyllite and schist clasts require a nearby source due to their

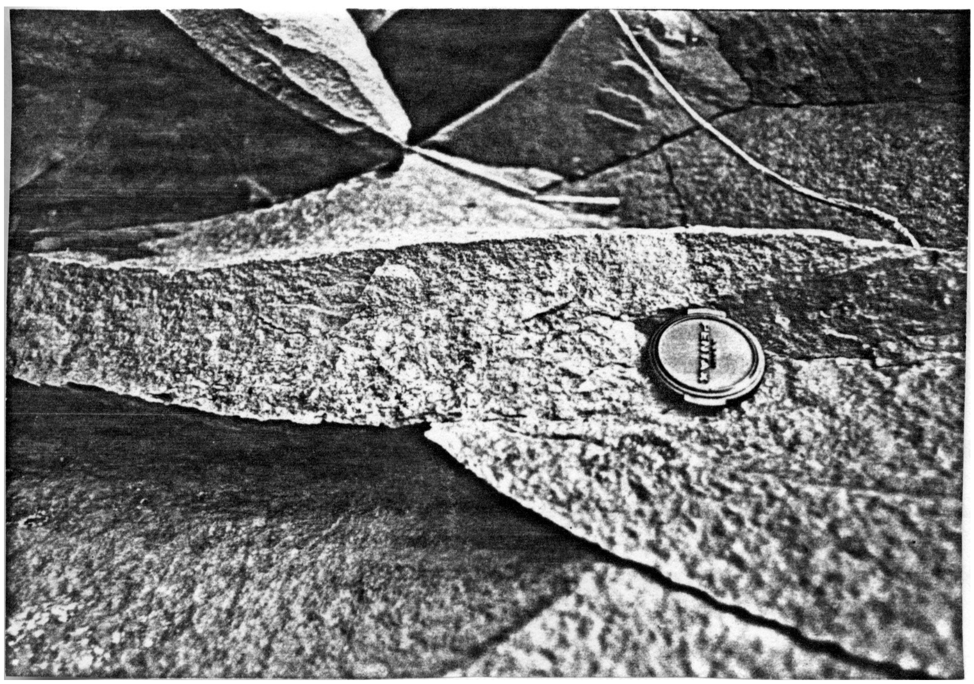


Figure 6.1 Shale rip-up clasts in bottom of turbidite bed.

rapid disintegration during transport (Cameron and Blatt 1971). To the east of the allochthonous continental rise sediments is a belt of multiply deformed rocks containing pelitic and psammatic phyllites (Rowley and Kidd 1981). These rocks were folded and thrusted during the Taconic Orogeny and are a likely source for the metamorphic fragments found in the turbidites.

Volcanic Clasts

The variety of volcanic compositions found in these samples (ranging from mafic to silic in composition) can be interpreted from common sense, and from data given by Dickinson and Rich (1972), Ingersoll (1978) and Dickinson and Suczek (1979) as being related to a volcanic arc. The rounded nature and paucity of these clasts indicates these volcanic fragments were not deposited immediately adjacent to their arc source but have been transported some distance. The volcanic terrane located in eastern Vermont and western New Hampshire is a probable source area for the volcanic fragments. The terrane consists of metamorphosed silicic, intermediate and mafic volcanics along with abundant volcaniclastics (Zen 1972). If this is considered to be the remnants of an island arc, the deeper plutonic parts of it may be a source for the fresh microcline and perthite found in the samples.

Paleocurrents

Directional sedimentary structures in turbidites are usually numerous, and useful indicators for determining paleocurrent directions. The ones plotted are from a combination of my own measurements and published data (Middleton 1965, Middleton 1968, Krueger 1963, Vollmer

1981). The data are plotted on two rose diagrams, the first (fig 6.2) for the Pawlet and Austin Glen flysch (basically east of Albany) and the second (fig 6.3) for the Schenectady/Frankfortflysch.

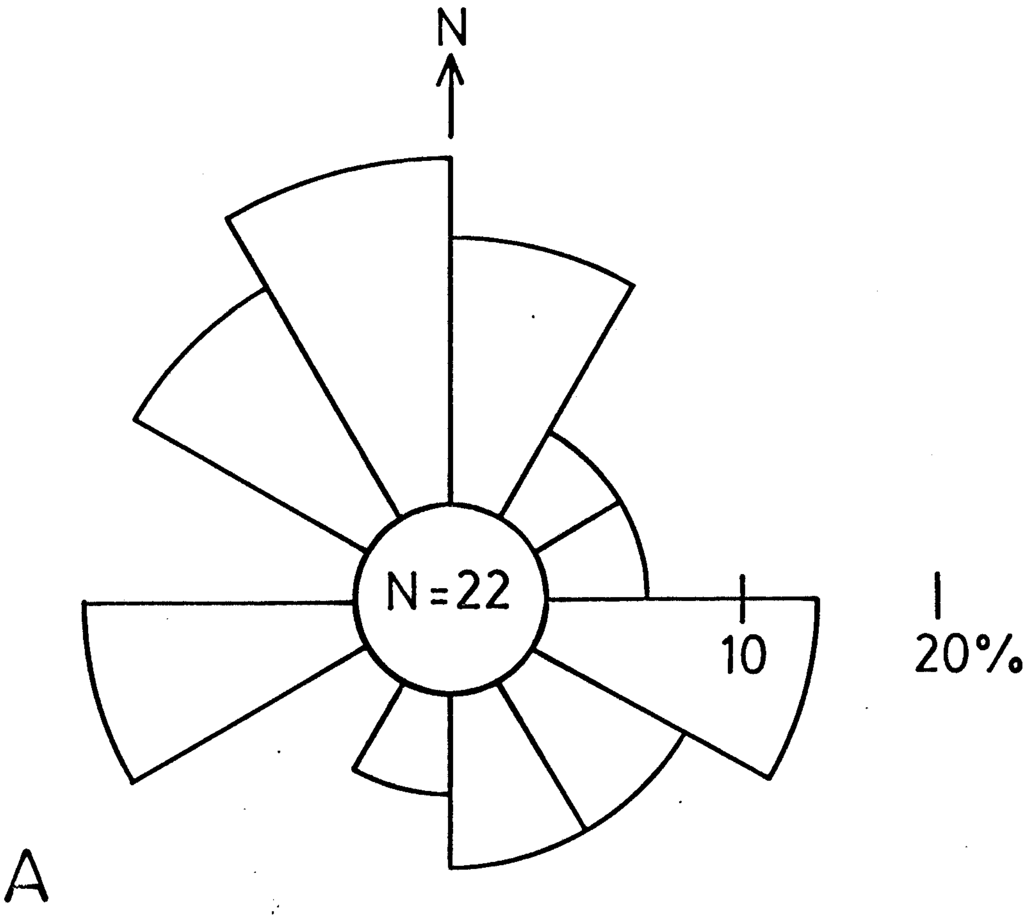
Examination of these diagrams shows that there is a change in both the paleocurrent direction and its consistency between the two areas. The allochthonous Pawlet and "parautochthonous" Ausitn Glen give a predominantly north-south flow direction with lesser east-west flow while the autochthonous Schenectady/Frankfort plot indicates a consistent northeasterly flow direction. While there are not enough data to draw a conclusion a possible explanation for these patterns lies in the nature of the depositional system of which these sediments are apart.

Walker and Mutti (1973) proposed a depositional model that integrates a number of individual facies into a single model for a submarine fan. This model has a main feeder channel, which has incised a slope, supplying detritus into a basin where a fan forms. The fan is divided into zones designated as upper, middle and lower fan. These divisions are identified by the distinctive type of sedimentary facies found in each. The proposed fan geometry along with the facies found in each is shown in figure 6.4. In this model classical turbidites (the alternating sandstones and shale of the flysch facies) are found in both the mid and lower fan areas.

While lack of outcrop makes it difficult to determine whether this is a practical model for the area studied, certain speculations can be made from the sedimentary features in those outcrops available for study and from the paleocurrent data.

Figure 6.2 (top) Paleocurrents from Pawlet and Austin Glen.

Figure 6.3 (bottom) Paleocurrents from Schenectady/Frankfort.


N
N=22
10
20%
A

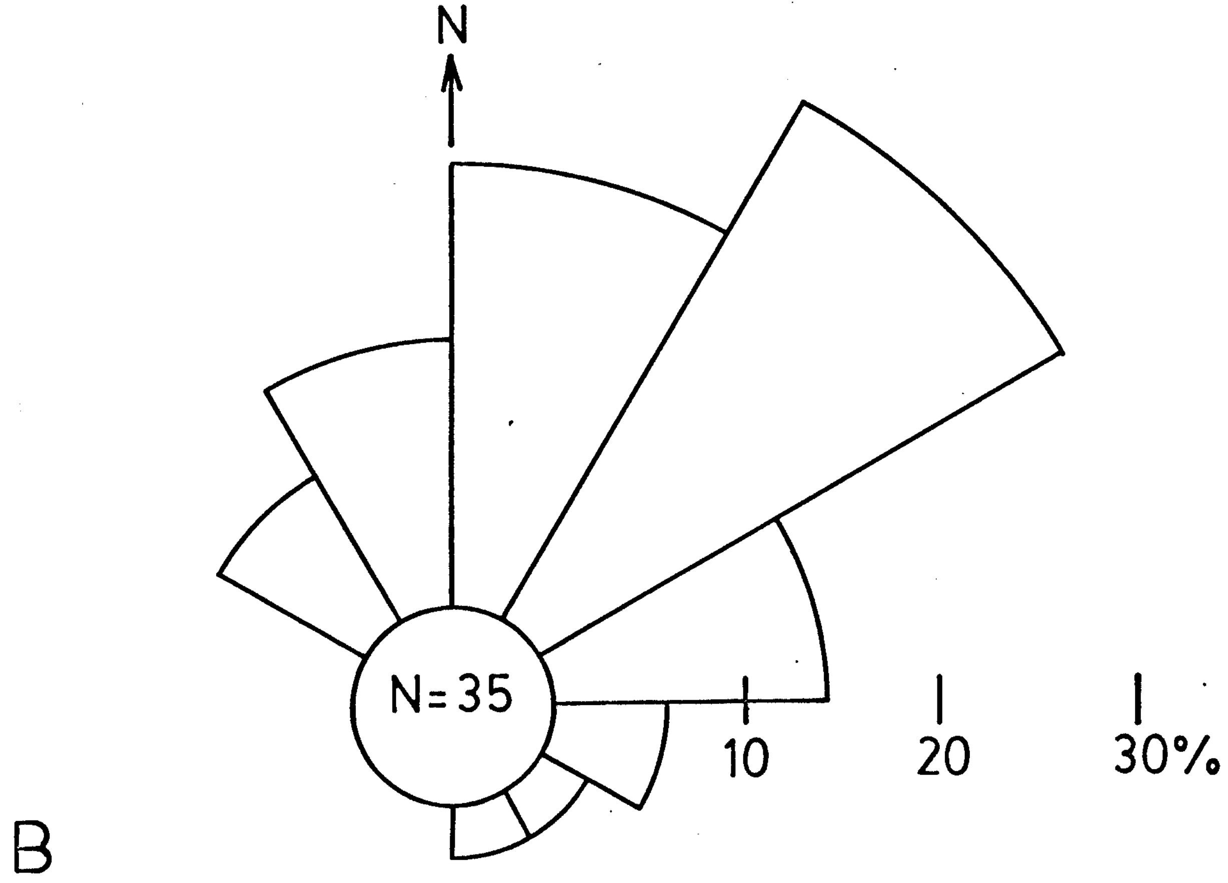
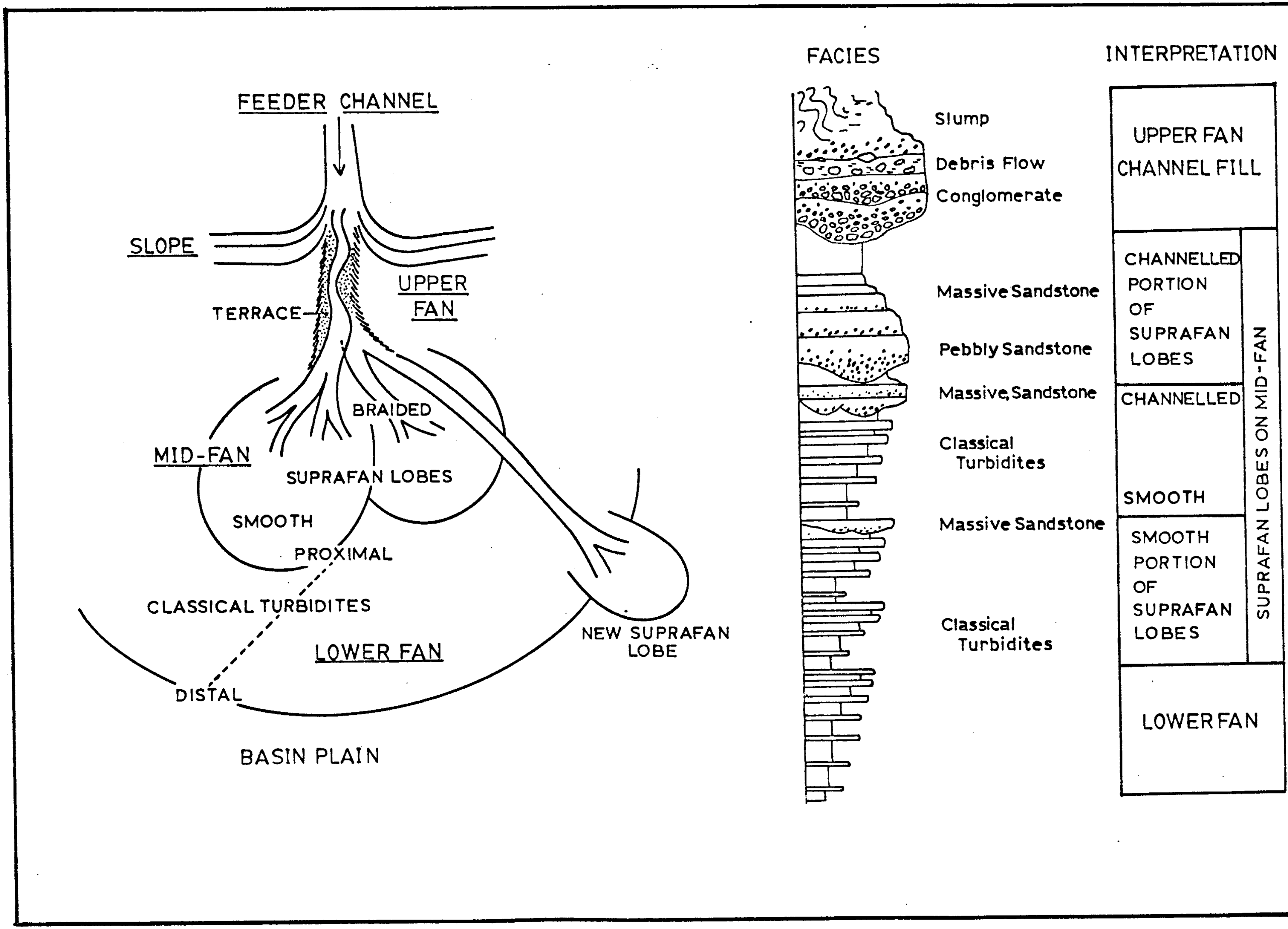

N
N=35
10
20
30%
B

Figure 6.4 Submarine fan model proposed by Walker and Mutti (1973).

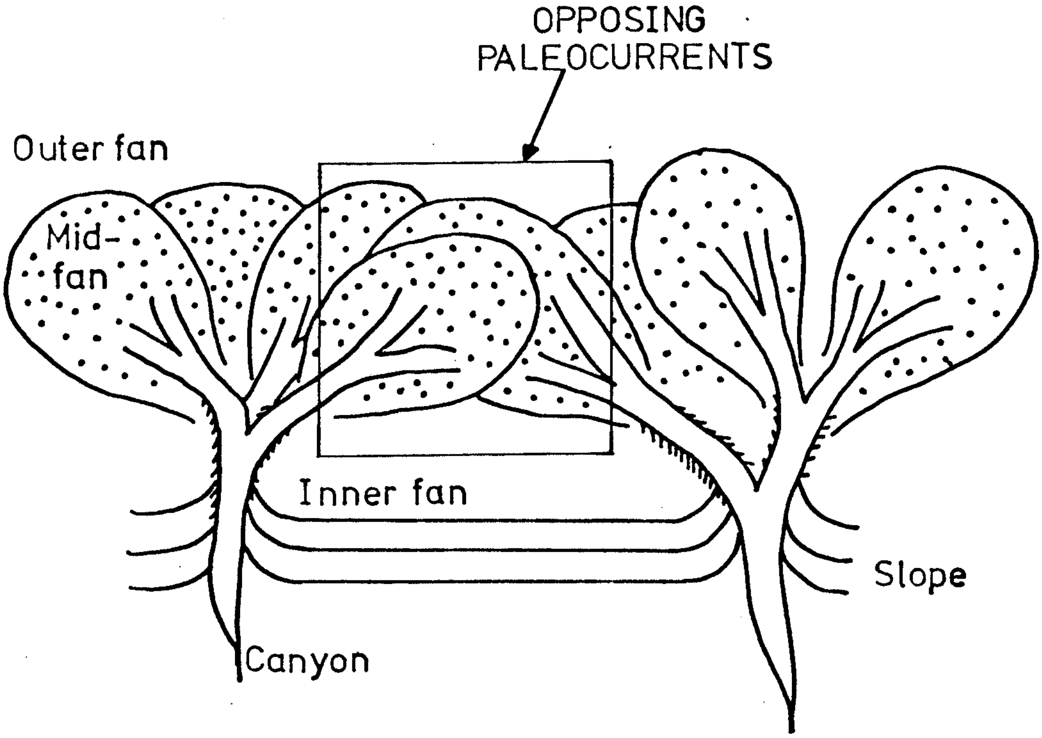

FEEDER CHANNEL
SLOPE
TERRACE
UPPER FAN
BRAIDED
MID-FAN
SUPRAFAN LOBES
SMOOTH
PROXIMAL
CLASSICAL TURBIDITES
LOWER FAN
NEW SUPRAFAN LOBE
DISTAL
BASIN PLAIN
FACIES
Slump
Debris Flow
Conglomerate
Massive Sandstone
Pebbly Sandstone
Massive, Sandstone
Classical Turbidites
Massive Sandstone
Classical Turbidites
INTERPRETATION
UPPER FAN CHANNEL FILL
CHANNELLED PORTION OF SUPRAFAN LOBES
CHANNELLED
SMOOTH
SMOOTH PORTION OF SUPRAFAN LOBES
SUPRAFAN LOBES ON MID-FAN
LOWER FAN

The current system of the older flysch in the eastern part of the study area appears to be distinctly different from that in the younger found in the west. Longitudinal transport of flysch parallel to the axes of troughs in orogenic belts is commonly seen (Graham et al 1975). Both sets of paleocurrents show transport roughly parallel to the regional strike of the Taconic orogenic belt. In the eastern areas the prominent paleocurrent flow direction is to the north. The subsidiary directions found in the rose diagram commonly occur in different beds of the same outcrop. This can be explained by having numerous small fans which overlap (fig 6.5). The paleocurrents from the western part of the area give a more consistent regional flow direction indicating a steady south to north depositional pattern indicating it is part of a larger fan system.

Plate Tectonic Setting

An attempt to determine the plate tectonic setting of sediments may be made by plotting the composition of the sediments on provenance diagrams (fig 6.6-6.9). The fields within these diagrams were determined empirically by plotting data from known tectonic settings (QFL, QmFLt, QpLvLsm: Dickinson and Suczek 1979, Dickinson et al 1983, LmLvLs: Ingersoll and Suczek 1979). The QFL and QmFLt diagrams each have three main fields, continental block, recycled orogenic and island arc, which have transitional subdivisions. The continental block sediments are quartzo-feldspathic sands poor in lithic fragments. The most quartzose sediments are from sediments recycled from the craton interior with the sands becoming more feldspathic due to basement uplift.

Figure 6.5 Overlapping submarine fans demonstrating ways to get opposing paleocurrents in adjacent outcrops (Hiscott 1977).


OPPOSING
PALEOCURRENTS
Outer fan
Mid-
fan
Inner fan
Slope
Canyon

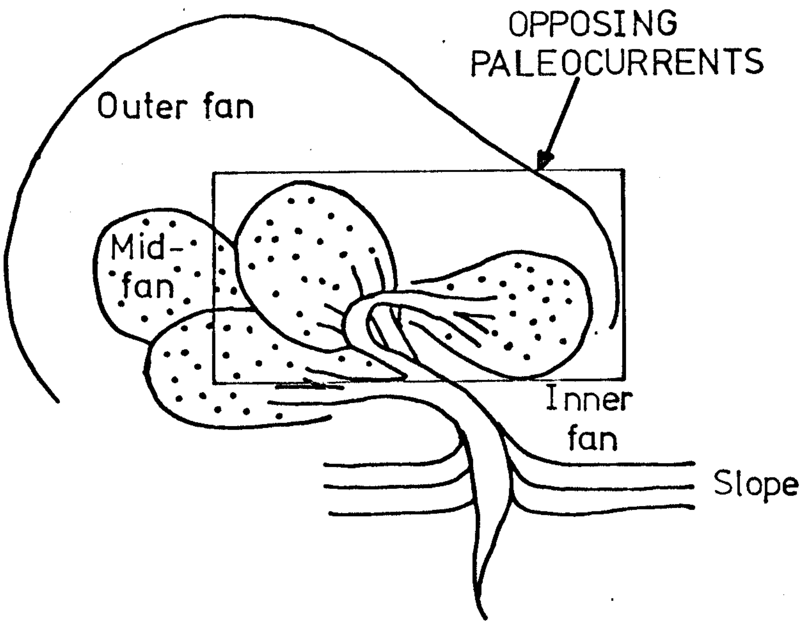
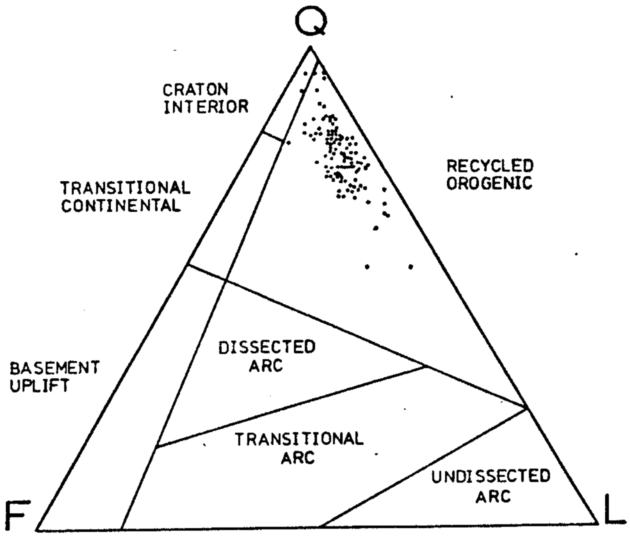
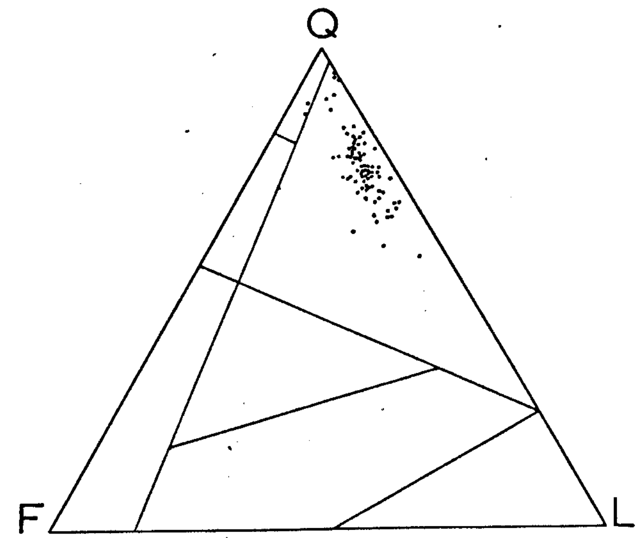

OPPOSING
PALEOCURRENTS
Outer fan
Mid-
fan
Inner
fan
Slope

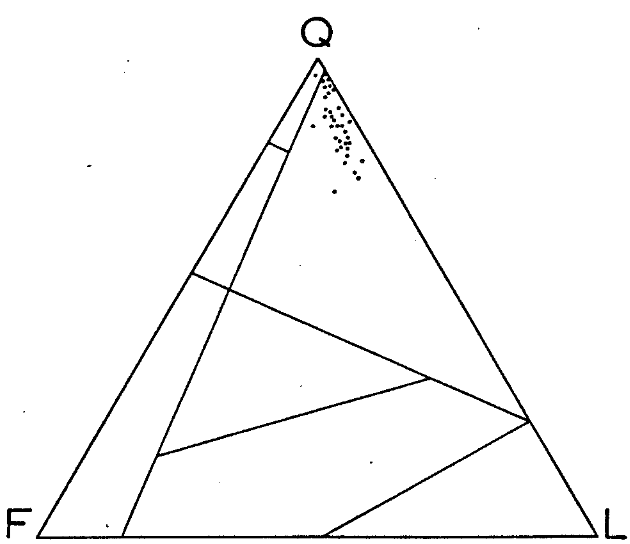
Figure 6.6 QFL diagram parameters:
Q = total quartzose grains including chert and quartzite
F = monocrystalline feldspar grains
L = polycrystalline lithic fragments including sedimentary, metamorphic and igneous varieties



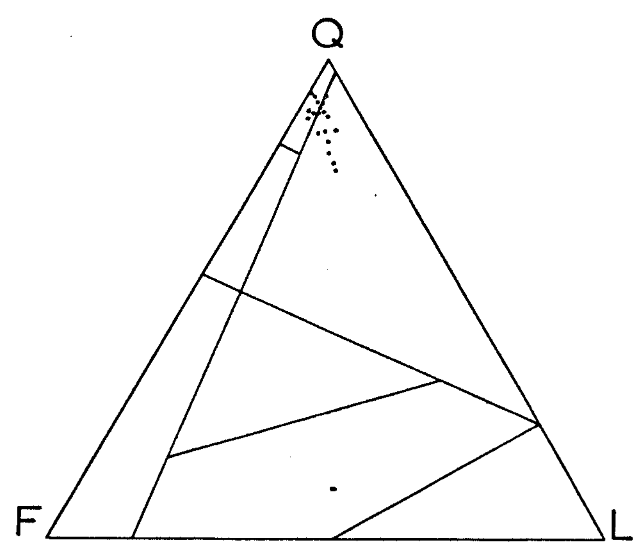
PAWLET
N=104



AUSTIN GLEN
N=78

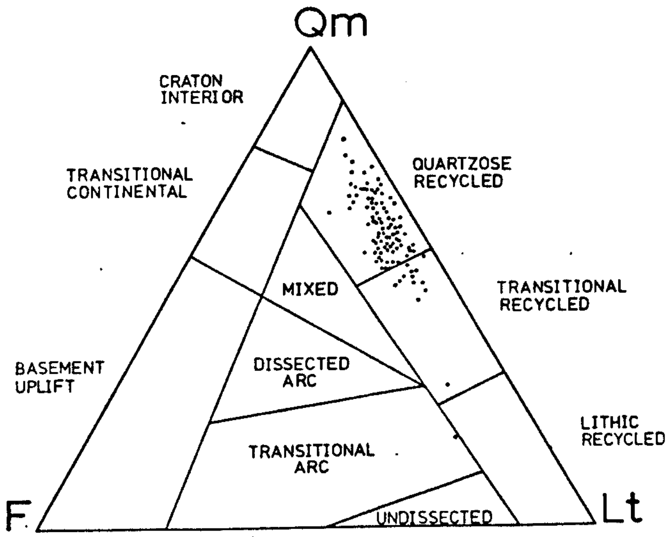


SCH/FRANK
N=32

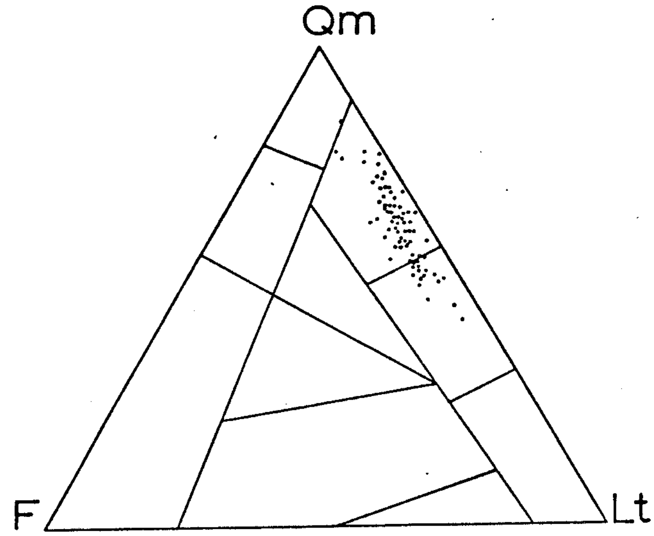


QUASSAIC
N=19

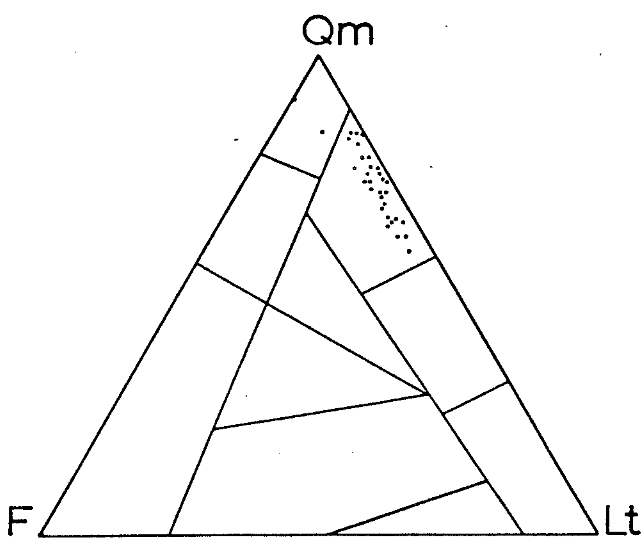
Figure 6.7 QmFLt diagram parameters:
Qm = monocrystalline quartz grains
F = monocrystalline feldspar grains
Lt = total polycrystalline lithic fragments including quartzose varieties



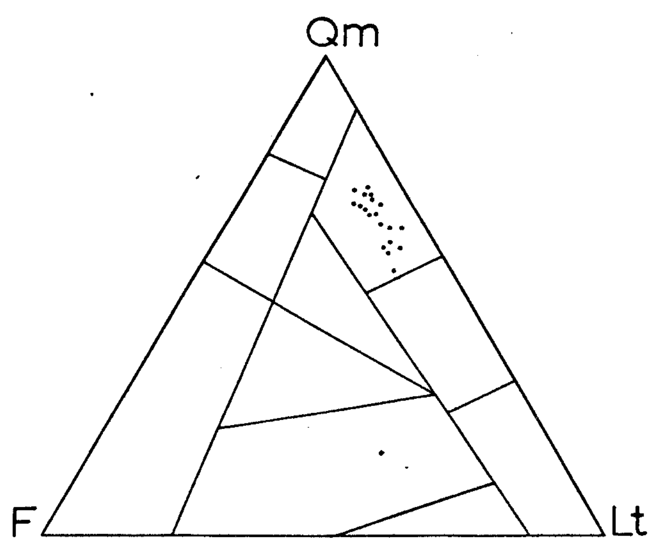
PAWLET
N=104



AUSTIN GLEN
N=78



SCH/FRANK
N=32



QUASSAIC
N=19

Figure 6.8 QpLvLs diagram parameters:
Qp = polycrystalline quartz fragments
Lv = lithic volcanic fragments
Ls = lithic sedimentary and metamorphic fragments

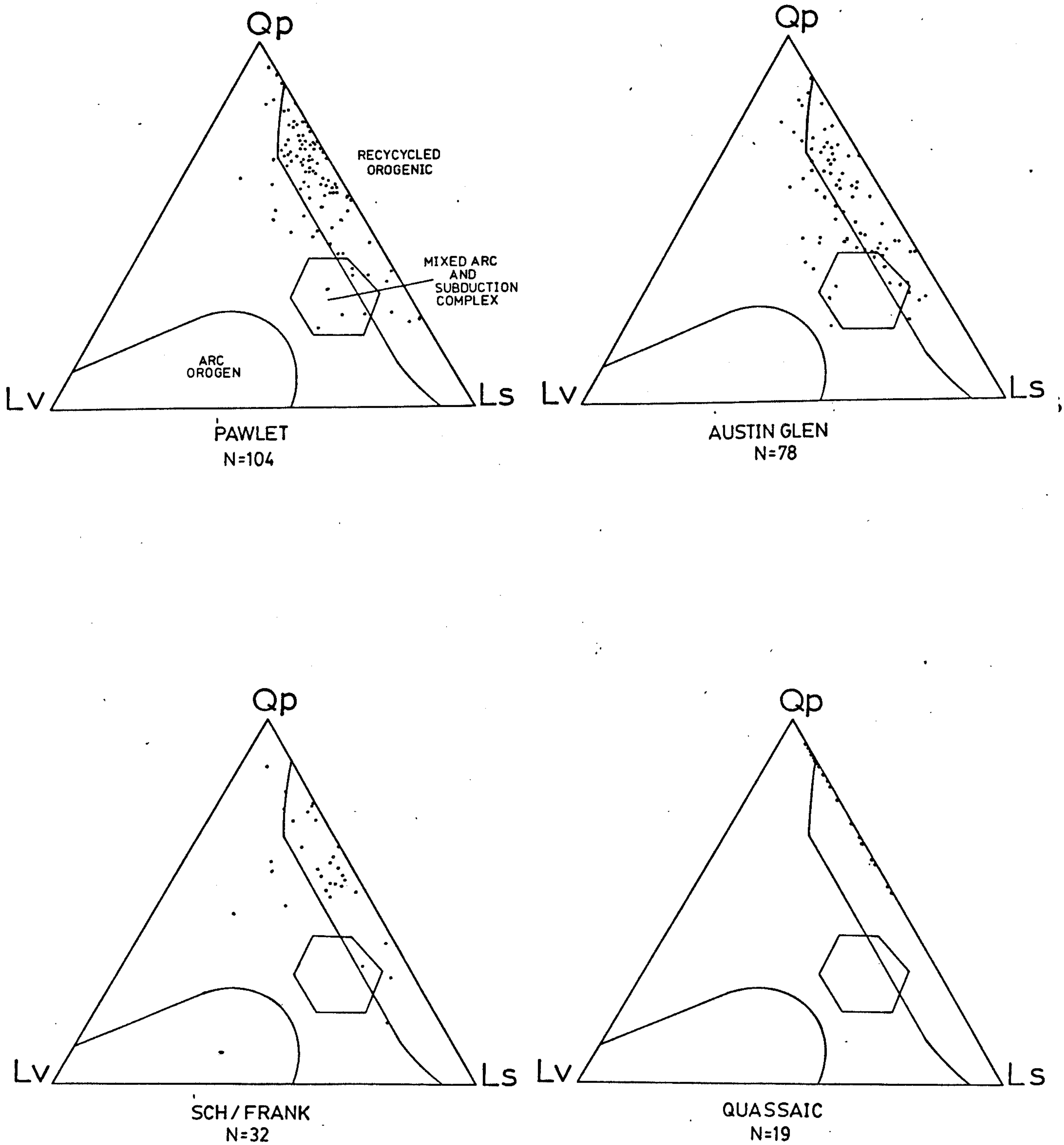
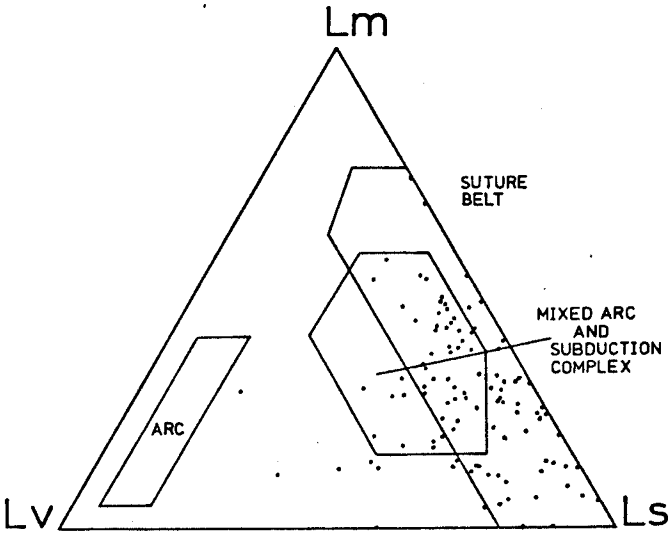
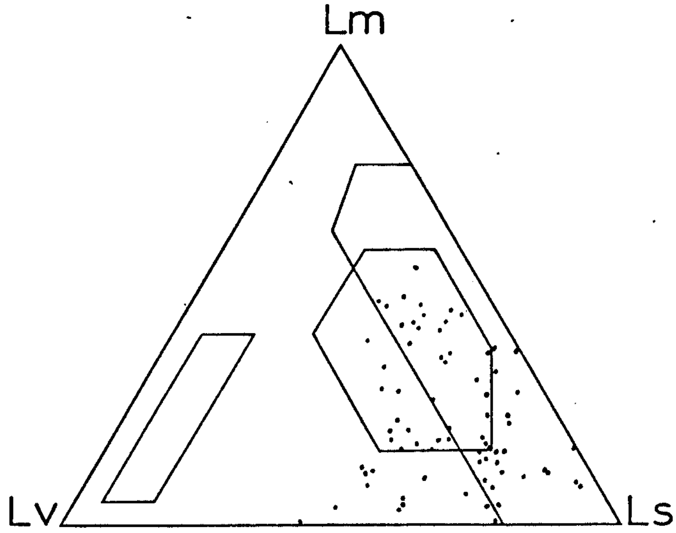

Qp
RECYCYCLED
OROGENIC
MIXED ARC
AND
SUBDUCTION
COMPLEX
ARC
OROGEN
Lv
Ls
PAWLET
N=104
Qp
Lv
Ls
AUSTIN GLEN
N=78
Qp
Lv
Ls
SCH / FRANK
N=32
Qp
Lv
Ls
QUASSAIC
N=19

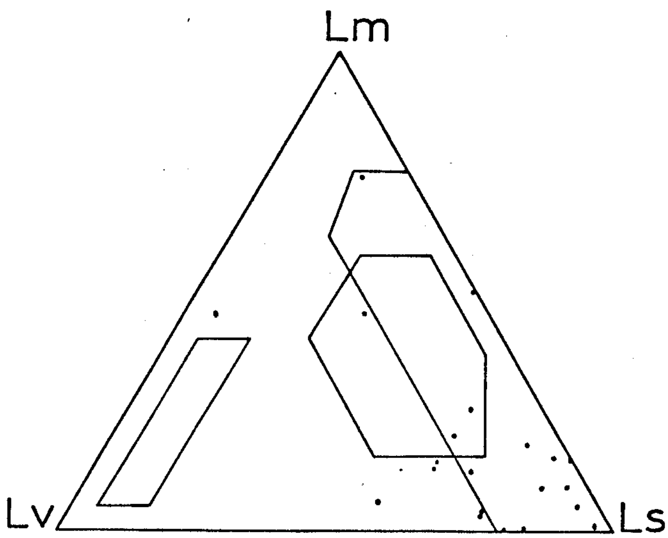
Figure 6.9 LmLvLs diagram parameters:
Lm = lithic metamorphic fragments
Lv = lithic volcanic fragments
Ls = lithic sedimentary fragments



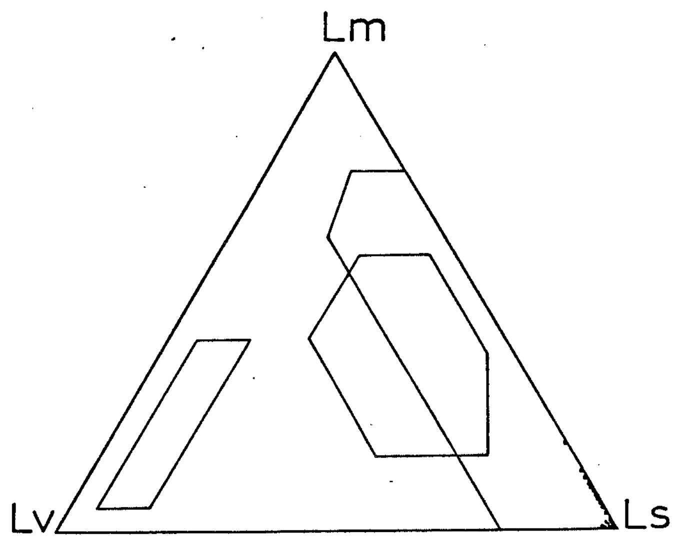
PAWLET
N=104



AUSTIN GLEN
N=78



SCH/FRANK
N=32



QUASSAIC
N=19

Magmatic arcs contribute igneous material ranging from fine-grained volcanics of the volcanic cover to plutonic fragments of the arc root. Minor amounts of sedimentary and metamorphic rocks are contributed from flanking areas. An undissected arc contributes mainly lithic fragments and as erosion dissects the deeper plutonic areas of the arc the detritus becomes more quartzo-feldspathic.

Recycled orogen provenances are folded and faulted rocks from which sedimentary and metasedimentary detritus is derived. Minor amounts of detritus from ophiolitic belts and magmatic arcs are often found. The tectonic settings of these sands include subduction complexes, suture belts and foreland fold-thrust belts. Sands from these sources are generally low in feldspar due to their primary source not being igneous (Dickinson and Suczek 1979).

The provenance plots of the samples studied indicate a recycled orogenic setting for these sediments. Dickinson and Suczek (1979) describe this type of high quartz low feldspar sediments as being from a collision orogen provenance. This involves nappes and thrust sheets of recycled cratonic sedimentary and metamorphic rocks with subordinate volcanics as a source and the sediment being deposited in a foreland basin.

CHAPTER SEVEN

RESULTS

As a result of an arc-continent collision during the Ordovician Taconic Orogeny clastic sandstones migrated first across the continental rise, then over the carbonate shelf that had developed on continental basement. An arc source is indicated by the variety of volcanic clasts found amongst the detritus. The collision of the volcanic arc with the continent is inferred to have caused the large influx of sand of which these sediments are composed.

The basin in which these sediments were deposited was elongate and parallel to the Taconic deformation front. The earliest paleocurrent pattern shows deposition taking place in relatively small overlapping fans with longitudinal flow parallel to the deformation front. As the foreland basin migrated westward from the Taconic thrust front a more consistent south to north paleocurrent pattern is displayed. This south to north flow pattern contrasts with a north to south direction in similar age sediments found to the north of Quebec. Graham et.al. (1975) demonstrated that in the Ouachitas and in the Himilayas a similar longitudinal flow was due to oblique collision occuring initially at one end of the orogenic belt, then proceeding in a scissoring fashion to close the remaining ocean. If a similar interpretation is made for the pattern seen in the foreland basin of the Taconic Orogeny it would suggest collision occuring initially to the north of Quebec and to the south of this study area with a shrinking basin located between.

Two different sandstone types are found. The earliest sediments are of flysch facies which consist of interbedded deep water turbiditic sandstones and shales. As the collision progressed the basin shallowed changing from flysch deposition to sandstones of molasse facies (Quassaic). Sampling was performed so as to have both an along strike and an across strike representation of compositions. The samples collected along strike are considered to be of similar age and show a consistent composition suggesting a similar source for all the samples of a particular age. The turbiditic sandstones of the flysch are lithic wackes which contain detritus from a variety of sources. Three main sources are hypothesized: sedimentary, metamorphic and volcanic. All three of these source types are found immediately to the east, the Cambrian-Ordovician continental rise facies being the sedimentary source, the earlier accretionary prism contributing the metamorphic clasts and the volcanic arc being the source of the volcanic detritus. The bulk composition of the flysch remained relatively constant through time and comparing the across strike sample compositions shows the only notable difference being an increase in the proportion of potassium feldspar found in the younger flysch.

The Quassaic contains abundant quartz, chert and sedimentary rock fragments but there is a notable lack of metamorphic and volcanic clasts. The sedimentary features found in outcrop and the textures seen in thin section show these rocks to be of other than turbiditic deposition. A possible exposure of a plutonic source is noted in these sediments due to the euhedral microcline and aggregates of polycrystalline quartz, plagioclase and biotite found. Also found in the sediments of the Quassaic are an abundance of carbonate clasts in association with fragments of the Indian River Formation (continental rise sediments of the Taconic Allochthon). These are the only sediments in which abundant carbonate material is seen. Two possible sources can be considered, the carbonate shelf formed on the continental side (eg. Beekmantown equivalents) or from an active carbonate bank formed in front of the volcanic arc. The sediments found in association with the carbonate material would not preclude either possibility but the lack of expected sediments from the continental side such as the Cheshire Quartzite would seem to favor the origin of these sediments being the volcanic arc carbonates.

Differences are noted between these sediments and similar sediments of Quebec and Newfoundland. While the detritus of these areas contain abundant chromite and serpentine which are indicative of an ophiolitic source neither of these is found in the sediments of the New England region. The detritus found in the samples studied give no evidence of an ophiolitic source contribution. This lack of ophiolitic detritus could indicate that the forearc was floored by continental rather than oceanic basement (Rowley 1983).

Minerals indicative of medium or higher grade metamorphism such as blue green amphibole, staurolite, andalusite, kyanite and garnet were not found. This suggests that the deeper levels of the Taconic orogen had not yet been exposed at the time of deposition of these sandstones.

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