Stratigraphy, Sedimentation and Basin Development of the Jacksonburg Limestone and Martinsburg Formation, Ordovician, northern New Jersey.

By STEPHEN GARRETT POLLOCK

A thesis submitted to

The Graduate School

of

Rutgers University

in partial fulfillment of the requirements

for the degree of

Doctor of Philosophy

Written under the direction of

Professor Raymond Murray

of the Department of Geology

and approved by

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New Brunswick, New Jersey

June 1975

ABSTRACT OF THE THESIS

Stratigraphy, Sedimentation and Basin Development of the Jacksonburg Limestone and Martinsburg Formation, Ordovician, northern New Jersey.

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The Jacksonburg Limestone and Martinsburg Formation is a depositional package. Physical stratigraphy of the Jacksonburg Limestone is complex. Thickness of the Jacksonburg Limestone ranges from 32-245 meters and thins to the northeast.

The Martinsburg is subdivided into a lower claystone Bushkill Member and an upper graywacke rich Ramseyburg Member. The Bushkill Member varies from 30-375 meters thick. The thickness variation is dependent upon geographic variation and initial deposition of graywacke beds. Ramseyburg Member ranges from 1320 to 1500 meters. The graywackes occur as large lenses within thin bedded claystone.

Together the Jacksonburg Limestone and Martinsburg Formation are interpreted as the filling of a starved basin in front of a west facing carbonate platform. Presumably, carbonate platform deposition began in Lower Cambrian time and continued until Lower Ordovician resulting in the Leithville Formation, Allentown Dolomite and Beekmantown Group. By Middle Ordovician Time the remanent platform top received a thin sequence of clastic carbonate shelf lithologies. Filling of the basin began during this time by deposition of carbonate slope and sub-

marine channel deposits of the Jacksonburg Limestone and non-carbonate hemipelagic clays and submarine fans of the Martinsburg Formation. During this phase of sedimentation large blocks of Cambro-Ordovician Limestone broke away from the carbonate platform edge and were emplaced by submarine sliding into the non-carbonate basin environment of the Martinsburg Formation. By Upper Ordovician time the basin had sufficiently filled so that preserved sediments were deposited in a relatively shallow water shelf environment.

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ACKNOWLEDGMENTS

The author is deeply indebted to Drs. Raymond Murray, Martha Hamil and Richard Olsson for their many suggestions and aid during the various stages of the thesis. Dr. Raymond Murray is acknowledged for originally suggesting the Martinsburg Formation as a potential thesis topic.

To my wife Jo goes an appreciation and thanks for her help and encouragement, understanding and steadfastness during graduate studies.

The Geological Society of America, Sigma Xi, the Scientic Research Society of North America, and the Department of Geology, Rutgers University, New Brunswick, New Jersey, is acknowledged for providing partial financial assistance during field and laboratory studies involved in the thesis.

INTRODUCTION

The Martinsburg Formation within New Jersey and Pennsylvania is part of a major Middle and Upper Ordovician sedimentary basin that extends from the Gaspé Peninsula in Quebec into the southeastern United States. Sedimentary environments within the Martinsburg Formation and its equivalents have been interpreted as deeper water flysch (Enos, 1969; McBride, 1962; McIver, 1970; Van Houten, 1954) and a shallow water shelf (Bretsky, 1969, F. J. Marcewicz, personal communication; Walker, 1970; and Willard, 1943). Also the Martinsburg and its equivalents has been reported to have served as recipient for a variety of allochthons or klippen in New York (Knopf, 1962; Zen, 1967; 1972b) and Pennsylvania (Platt and others, 1972; Stose, G.W., 1946) with wildflysch-type conglomerates locally developed.

Recent studies of the Martinsburg Formation in New Jersey and eastern Pennsylvania have centered around stratigraphic (Drake and Epstein, 1967) or structural problems with special emphasis on the origin of slaty cleavage (Alterman, 1973; Carson, 1968; Drake, 1969; Epstein and Epstein, 1969; and Maxwell, 1962). In Pennsylvania, Cambro-Ordovician Limestone units mapped as a facies of the Martinsburg Formation by Miller (1937a) were reinterpreted by Aldridge (1967) as submarine slide blocks and are considered by Platt and others (1972) as part of the Hamburg Klippe. Similar Cambro-Ordovician limestone units were mapped within the Martinsburg outcrop belt by Bayley and others (1914) and interpreted by them as folded remanents of a once more regionally extensive thrust sheet.

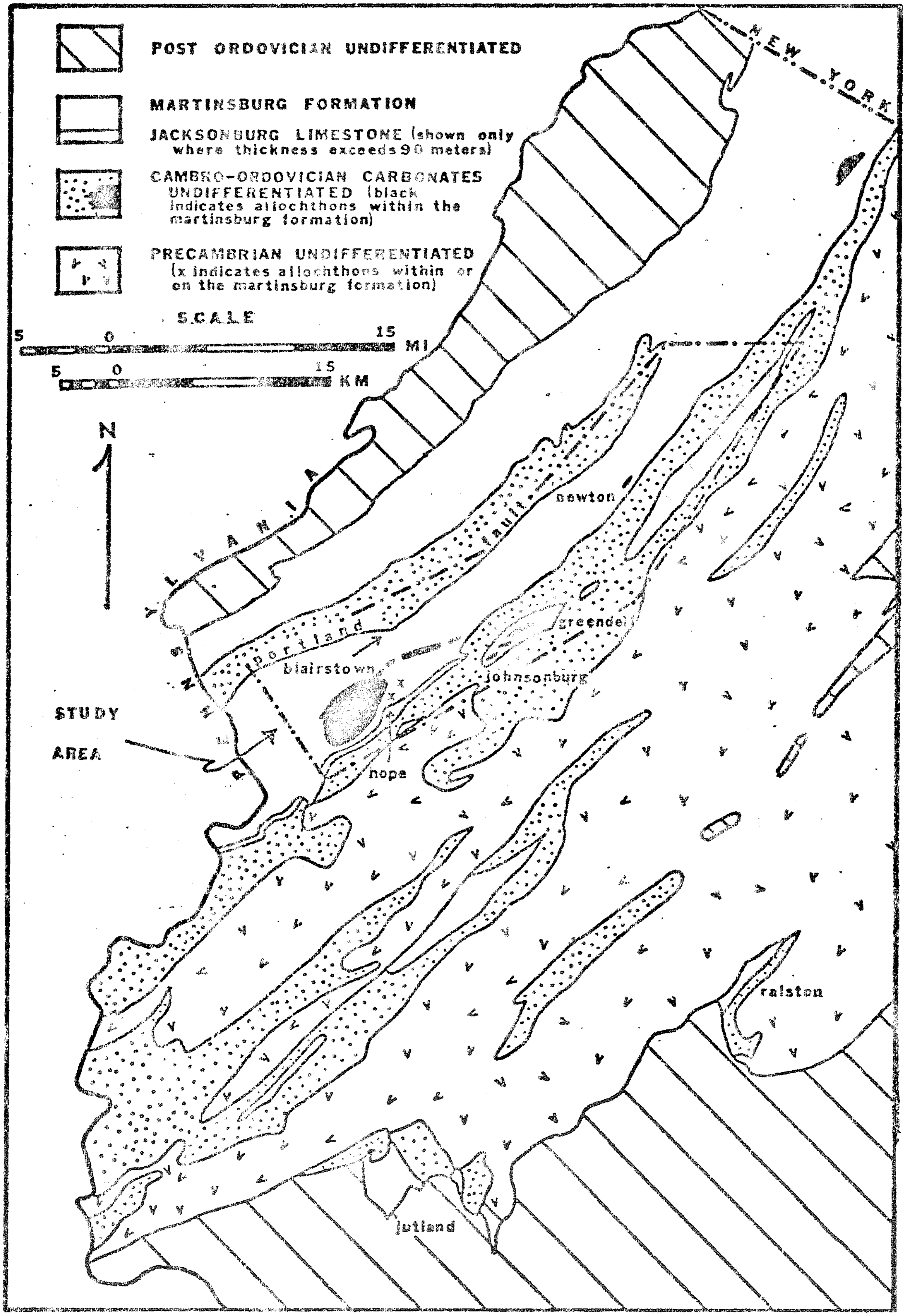

Figure 1 - Geologic sketch map of northern New Jersey

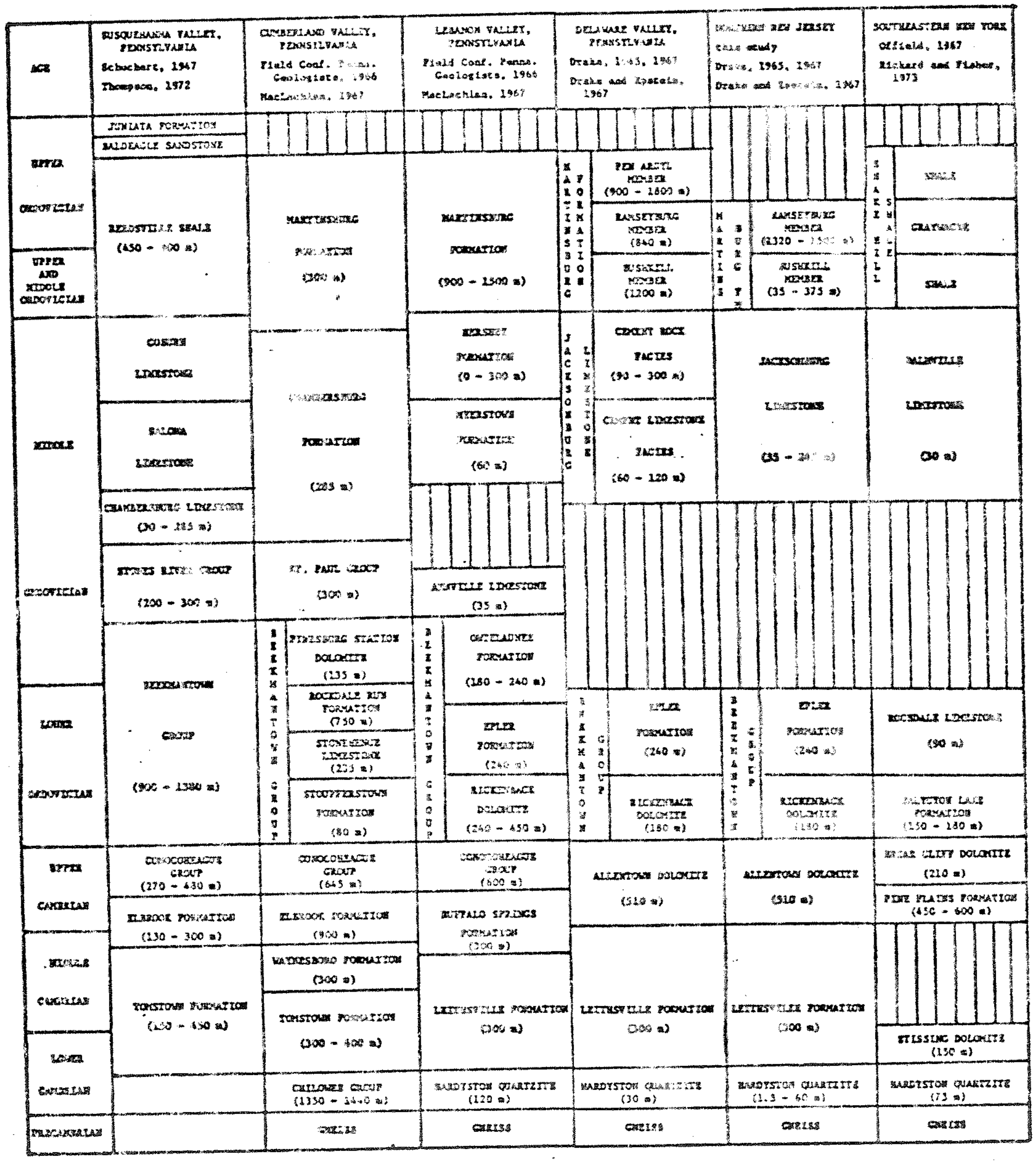

Figure 2 - Correlation of stratigraphic columns for the Lower Paleozoic from southeastern New York to central Pennsylvania

This paper examines the Jacksonburg Limestone and Martinsburg Formation in northern New Jersey in terms of regional stratigraphy and depositional environments. Special emphasis is placed on the allochthonous Cambro-Ordovician limestone units within the Martinsburg outcrop belt in terms of delineating a sedimentary or tectonic origin. The study proposes to demonstrate that the Jacksonburg Limestone and Martinsburg Formation is a depositional package that represents sedimentation and basin filling adjacent to a west facing carbonate bank. During the course of the study it became apparent that the Martinsburg Formation is sufficiently varied in terms of lithology, sedimentary structures and faunas to suggest that deposition occurred in both shallow and deeper water environments. Stratigraphic and geographic distribution of these elements has produced conclusions pertaining to regional sedimentation patterns throughout Middle and Upper Ordovician time in terms of changing depositional environments and paleogeography.

PREVIOUS WORK

The Jacksonburg Limestone, originally the Trenton Limestone of Weller (1901) was named by Spencer and others (1908) with Jacksonburg, New Jersey, as the type locality. The name has since been consistently applied to the high calcium fossiliferous limestone of Middle Ordovician (Trenton) age (Kummel, 1901; Weller, 1901; Spencer and others, 1908; Bayley and others, 1914; Miller, 1937b; and Barnett, 1965).

In eastern Pennsylvania, Miller (1937) subdivided the Jacksonburg into a lower "cement limestone facies" and an upper "cement rock facies". Miller and this study did not subdivide the Jacksonburg in New Jersey as in Pennsylvania. In southeastern New York the Jacksonburg equivalent, the Balmville Limestone is discussed by Offield (1967). Ray and Gault (1961) discuss the stratigraphy and mineralogy of the Jacksonburg in eastern Pennsylvania.

In New Jersey, Spencer and others (1908) first applied the term Martinsburg to shales, slates and graywackes previously referred to as the Hudson River Slate (Weller, 1901). Drake and Epstein (1967) gave formation status to the Martinsburg in eastern Pennsylvania and western New Jersey. They recognized three members (figure 2); a lower claystone Bushkill Member, a middle graywacke rich Ramseyburg Member, and an upper thick-bedded claystone slate Pen Argyl Member. Summaries in changes in the status of Martinsburg stratigraphy are given by Drake and Epstein (1967) for Pennsylvania and by Berry (1970, 1973) and Richard and Fisher (1973) and Offield (1967) for New York.

STRATIGRAPHIC FRAMEWORK

JACKSONBURG LIMESTONE

Lithofacies of the Jacksonburg consist of wackestone, minor packstone and grainstone, mudstone, pebble, cobble, and boulder conglomerate. Lithofacies distribution is variable, complex and is not consistent with the subdivision established by Miller (1937b) in eastern Pennsylvania. The general stratigraphy is a local basal pebble conglomerate followed successively by wackestone or packstone and calcareous silty claystone. Where the basal conglomerate is not present, the base is calcareous mudstone (Spencer and others, 1908; Miller, 1937b) or more commonly wackestone.

Cobble and boulder conglomerate horizons at the base, middle and top of the formation are interbedded with mudstone and wackestone and are restricted to localities east and south of Hope, New Jersey. Conglomeratic wackestone occurs higher in the formation to the east and west of Hope, New Jersey and in Newton, New Jersey, but is not present at other localities higher in the section.

The Jacksonburg-Martinsburg contact is gradational throughout the area. In the southwestern area, the Jacksonburg Limestone grades from wackestone through calcareous, sparsely fossiliferous mudstones into the non-calcareous claystone of the Bushkill Member of the Martinsburg Formation. To the northeast, the transition is more abrupt covering a shorter stratigraphic interval. The highest Jacksonburg beds exposed consist of wackestone with 60% matrix. In the vicinity of Hope, New Jersey, Jacksonburg wackestones interbed with thin to medium beds (4-30 cm) of black calcareous and dolomitic claystone of the Bushkill Member. The dolomite in these claystones is detritus derived from Cambro-Ordovician carbonates.

Thickness of the Jacksonburg ranges from approximately 95 meters in the southwestern area to 35 to 40 meters in the northeastern area. Approximately 2 km southeast of Hope, New Jersey, a maximum thickness of 245 meters is present. The abnormally high thickness here is sedimentary thickening. Minor secondary tectonic thickening is also present due to faulting. Sedimentary thickening of the Jacksonburg section also occurs within Newton, New Jersey. Maximum thickness is approximately 60 meters contrasted with the average of 35 - 40 meters in surrounding areas. The abnormally thick Jacksonburg section in these two areas contains thick massive beds of pebble, cobble and boulder conglomerate.

MARTINSBURG FORMATION

In northern New Jersey the Martinsburg Formation is subdivided into a lower claystone Bushkill Member and an upper graywacke-rich Ramseyburg Member. An upper thickbedded claystone member, the Pen Argyl equivalent, is not present having been eroded away, faulted out, or not deposited (figure 2). Locally the Ramseyburg Member may be subdivided into an informal lower unit consisting of laminated claystones with minor graywacke, and an upper unit consisting of cycles of graywacke interbedded with laminated claystone. In northeastern areas the Ramseyburg is in its entirety more cyclic and in general has a higher silt and sand content (figure 3). The cyclic nature, lenticular geometry, and irregular geographic distribution of the graywacke intervals in the Ramseyburg has precluded further subdivision. Average cumulative thickness for the Martinsburg is between 1620 and 1710 meters.

Bushkill Member

Lithofacies of the Bushkill Member is uniform consisting of very fine grained claystone and slate and minor thin graywacke beds less than 20 cm thick. Mineralogically the Bushkill contains 2M mica, chlorite, quartz and minor albite.

Drake and Epstein (1967) placed the contact between the Bushkill and Ramseyburg Members beneath the lowest prominent (30 cm) graywacke bed. This definition has been consistently applied. Thickness of the Bushkill ranges from 0 to 375 meters. The maximum thickness is less than that proposed by Drake and Epstein (1967) for the Bushkill in western New Jersey and eastern Pennsylvania where a maximum thickness of 1200 meters is proposed. In northern New Jersey the variation in thick-

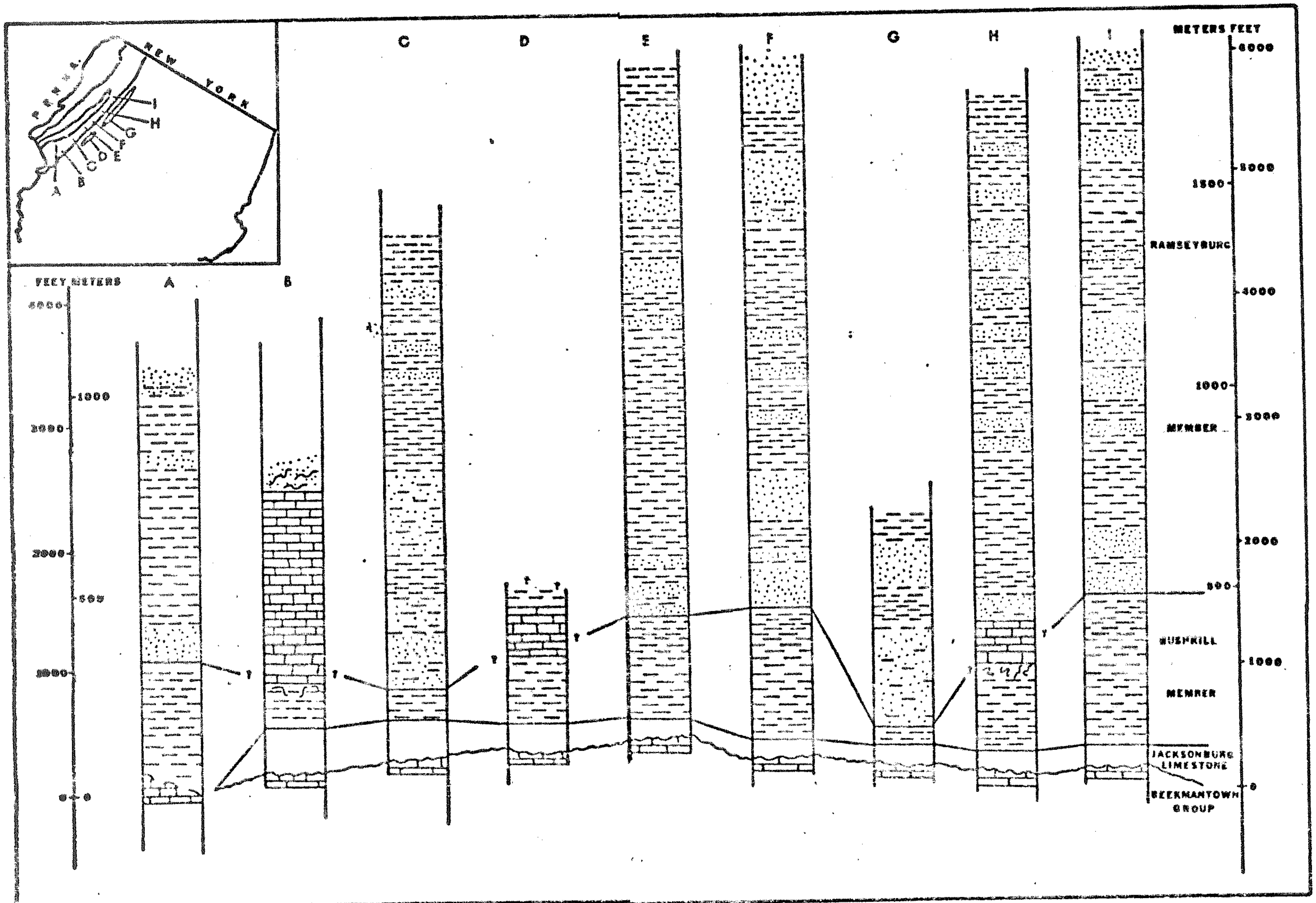

Figure 3 - Idealized stratigraphy and lithologic distribution within the Martinsburg Formation in northern New Jersey. Dash pattern is claystone, stiple pattern graywacke, block pattern Cambro-Ordovician carbonates and contorted dash pattern slumped Martinsburg Formation.

ness is due to (1) faulting and (2) the fact that the Bushkill-Ramseyburg contact is a facies contact, that varies geographically.

North of Johnsonburg, New Jersey, the Jacksonburg Limestone and the Bushkill Member are faulted out so that the Epler Formation of the Beekmantown Group (figure 2) and, locally, the Jacksonburg Limestone are in contact with graywackes or claystone of the Ramseyburg Member. In the vicinity of Blairstown, New Jersey, along the Portland Fault, the Bushkill thins by faulting to the northeast. Where fully developed the Bushkill ranges from 35 to 375 meters.

Sedimentologic variation in thickness is shown by a northwest thickening of the Bushkill into the Martinsburg basin, and also by thickening to the northeast and southwest of Hope, New Jersey (figure 3). Thickness variation is due to the deposition of small, possibly coalesing, lenticular graywacke cycles of the Ramseyburg Member, and partially to allochthonous (submarine slides) shale and graywacke, Cambro-Ordovician dolomite and Precambrian gneiss. Also proximity to submarine channels of the Jacksonburg Limestone appears to have had some control on Bushkill thickness.

Ramseyburg Member

Lithofacies of the Ramseyburg Member is laminated claystone and graywacke. The laminated claystones differ from Bushkill claystones in that they appear in general to be coarser grained and more thinly bedded (0.5 to 2.5 cm average). Mineralogically Ramseyburg and Bushkill claystones are identical. Graywacke lithofacies consists of fine grained silt to medium sand size material with variable amounts of matrix (22-67%). McBride (1962) discusses the petrography in detail.

Stratigraphy and lithofacies distribution of the Ramseyburg Member is highly complex. The complexity results from local variations in sediment types and large to medium scale allochthons positioned at different stratigraphic levels. Folding, faulting, poor exposure and lack of marker beds or horizons and subsurface data have prohibited detailed stratigraphic analysis of individual sandstone beds. In general however, thick sand beds probably are not continuous for great distances. Thick, 1 meter, sand beds within graywacke cycles at widely separated localities terminate abruptly. These pinch out or become noticeably finer grained and thinner over distances of several meters or tens of meters.

Graywackes are cyclically interbedded with claystone. Graywacke cycles are broadly lenticular in geometry. Lenticles range in thickness from less than 15 meters to more than 500 meters. Laterally the thicker cycles appear to extend from approximately 2 to 7 km. These cycles show complicated facies patterns of vertical interbedding and lateral interfingering with claystone. Thin graywacke cycles, thicken laterally into larger cycles, or are small individual lenses. Graywacke cycles terminate by pinching out, grading into adjacent claystone or both.

Preserved Ramseyburg thickness ranges from approximately 1320 to 1500 meters, averaging 1350-1385 meters. Variation in thickness estimates for the Ramseyburg is the result of geographic differences in fold style and fold intensity as well as local faulting. A thicker section is believed preserved in the vicinity of Newton, New Jersey. This greater preserved thickness is due to a northeast plunging syncline and movement along the Portland Fault which passes through the syncline core to the northwest.

ALLOCHTHONOUS SEQUENCE

Within the Martinsburg outcrop belt of northern New Jersey, Bayley and others (1914) mapped several allochthons of Cambro-Ordovician limestone and quartzo-feldspathic gneiss. These were interpreted by them to be remnants of a once continuous thrust sheet folded into a synform. Re-examination of allochthonous areas with particular emphasis on the Martinsburg surrounding the allochthons produced evidence that the dolomite and gneiss are within the Martinsburg rather than overlying it, and that much of the Martinsburg proximal to the dolomite and gneiss is also allochthonous.

Structural data indicates allochthonous areas were folded during regional f_1 folding which was accompanied by development of slaty axial plane cleavage. Pre-fold emplacement is shown by local folding of the allochthons into a form consistent with the regional fold pattern, local development of slaty axial plane cleavage in basal portions of the dolomite blocks, and local transposition of dolomite bedding parallel to cleavage.

Characteristics of allochthonous Bushkill and Ramseyburg which differentiate them from the autochthonous sequence are: (1) chaotic discontinuous bedding where bedding terminates by abrupt gradation into non-bedded material or planar surfaces (figure 4), (2) fold axes diverge in trend and plunge from regional tectonic fold axes (figure 5), (3) folds not properly aligned with slaty axial plane cleavage or convergent fan cleavage.

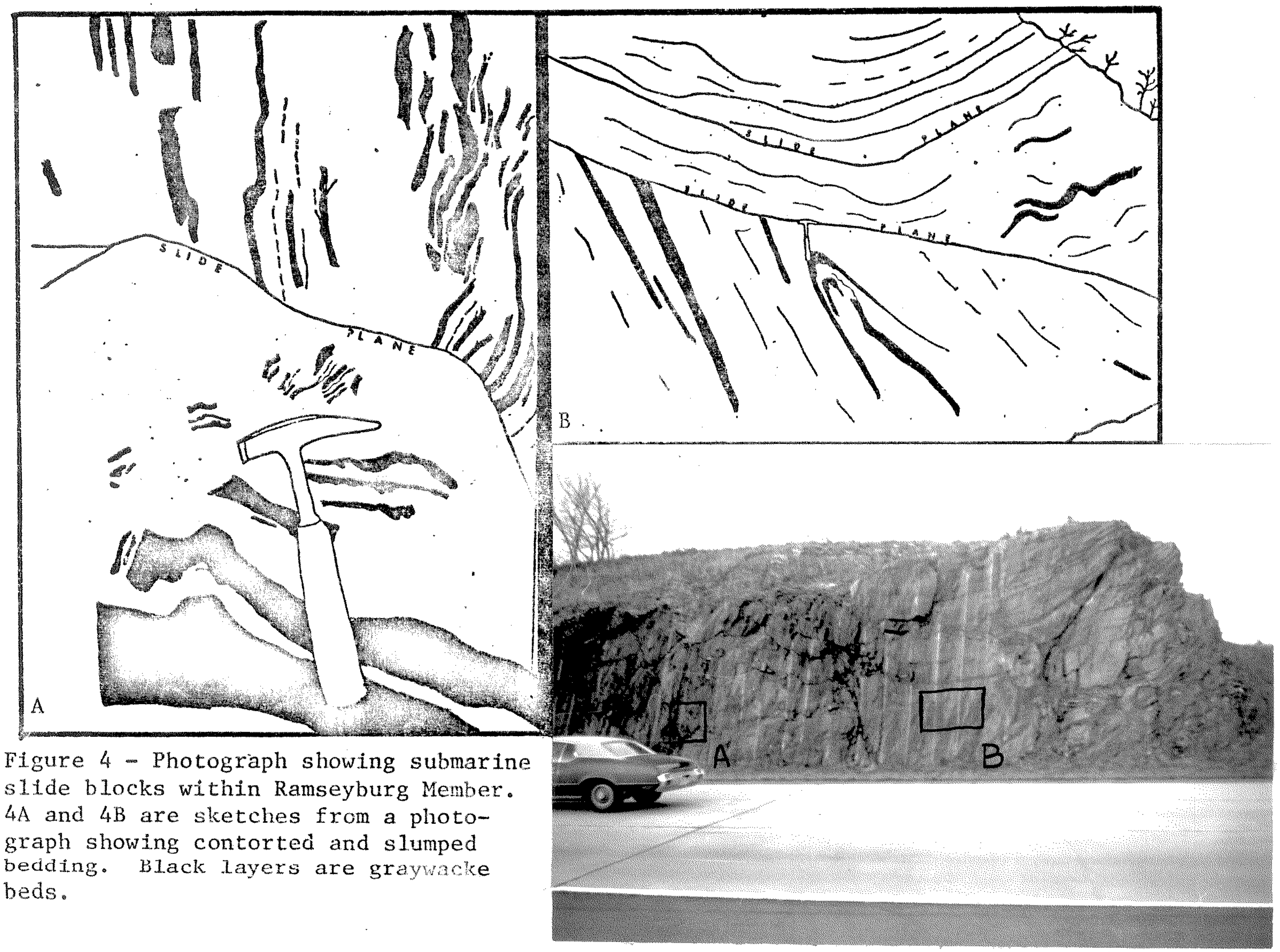

Figure 4 - Photograph showing submarine slide blocks within Ramseyburg Member. 4A and 4B are sketches from a photograph showing contorted and slumped bedding. Black layers are graywacke beds.

Chaotically bedded Martinsburg is a mappable unit, and is best developed lateral to and stratigraphically above dolomite blocks. Martinsburg exposed below the blocks is typically unbedded. Sand lenses parallel to cleavage may be remnant bedding, but are probably transposition structures. Shale blocks with thin graywacke beds or laminae are traceable for maximum distances of approximately 10-15 meters. Bedded areas commonly grade abruptly into nonbedded shale blocks. Termination of this type is loss of coherency of bedding and mixing or homogenization of textural types. Chaotic Ramseyburg with abundant graywacke beds exhibits bedding abruptly terminate by planar surfaces such that each surface marks a small scale angular unconformity (figure 4). These surfaces are differentiated readily from tectonic faults by lack of: (a) mineralization; (b) small, lenticular or sigmoidal mineralized fractures; (c) chloritization and (d) slickensides all of which are commonly associated with tectonic faults and fractures. Also the attitude of slaty cleavage does not change across the planar surfaces as it does across tectonic faults.

Folds attributed to sedimentary origin are common within chaotic blocks. Fold limbs are commonly terminated by one of the ways described above. Fold style and orientation is not consistent with small scale tectonic folds. The majority of tectonic folds have axial orientation N 40° E to N 60° E and plunge less than 12° north or south (figure 5). Sedimentary folds have a wide range of axial trends and plunges. These fold axes generally plunge more steeply than tectonic fold axes (figure 5). Tectonic folds have a conspicuous axial plane or convergent fan slaty cleavage, are recumbent or asymmetrical with a steeply dipping northwest limb. Sedimentary folds in chaotic areas

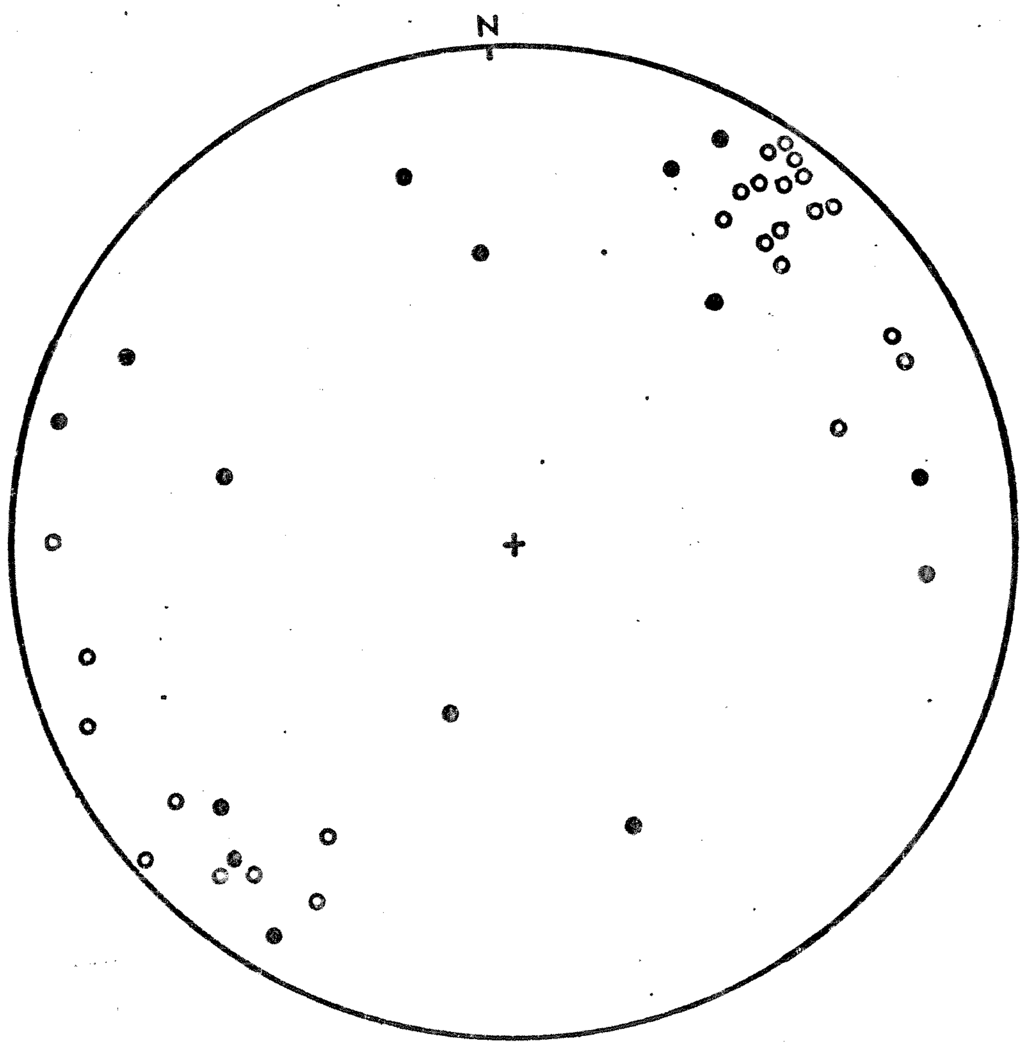

Figure 5 - Wulff net projection of selected tectonic fold axes (open circles) and sedimentary (slump) fold axes (closed circles). Partial girdle of the tectonic fold axes is due to f_2 folding. The orientation of the sedimentary fold axes does not show preferred or a partial girdle orientation.

do not show this type of cleavage or fold style (figure 4). Slaty cleavage is present, but not as axial plane or converging fan cleavage. The cleavage passes through the fold in a variety of orientations.

Carbonate allochthons within chaotically bedded Martinsburg are identified as Late Cambrian Allentown Dolomite and, to a much lesser extent, Lower Ordovician Rickenback Dolomite (figure 2, columns 4 and 5). Summaries of autochthonous Allentown Dolomite stratigraphy and petrography are given in Drake (1965, 1969) and Zadnik (1960). Allochthons identified as Allentown are composed of light medium gray to dark medium gray, fine to coarsely grained dolomite with local sandy dolomite and dolomitic shale intervals. Oolite and stromatolite beds are abundant in most exposures. Rickenback Dolomite occurs in the two largest allochthons. Rickenback lithology consists of medium bedded coarse crystalline dolomite with thin, discontinuous dark gray chert lenses.

Two small poorly exposed and weathered bodies of quartzofeldspathic gneiss constitute the third formation in the allochthonous sequence. The rocks are massive, and foliation is poor or absent. The gneisses are equigranular and are composed of plagioclase (oligoclase), quartz and biotite, in decreasing order of abundance.

Four individual allochthonous areas are indicated in figure 1. The allochthons are irregular in thickness and lateral extent, are widely distributed geographically, and occur at various stratigraphic levels. This is due to variations in original geometry, size, stratigraphic position of emplacement, erosional uncovering and preservation.

Geometry of the allochthons is broadly lenticular. Stratigraphic thickness is variable within individual allochthons. For example within the Greendell - Johnsonburg area thickness of the Allentown Dolomite varies from approximately 120 to 300 meters, and near Hope, New Jersey, thickness of the Allentown - Rickenback sequence ranges from 25 to 450 meters. Similarly lateral extent of the allochthonous areas is variable. The largest allochthon, north of Hope, New Jersey, is approximately 11 km in length, but the smallest allochton, northeast of Newton, New Jersey, is approximately 2.2 km long.

Position of emplacement of the allochthons is also variable. In general they are emplaced within the lower portion of the Martinsburg section. The allochthons near Hope, New Jersey, and Newton, New Jersey, locally transect, or approximately coincide with, the Bushkill-Ramseyburg contact.

Pretectonic folding of the Bushkill and Ramseyburg members is also variable. Minor pretectonic folding occurs in association with the carbonate allochthons in the Greendell - Johnsonburg area, and extensive pretectonic folding occurs in association with the carbonate allochthons near Hope, New Jersey and Newton, New Jersey.

Pretectonic slumping and sedimentary folding of the Martinsburg accompanied by incorporation of Allentown and Rickenback Dolomite and quartzo-feldspathic gneiss within the Martinsburg are best explained as having been emplaced by submarine sliding within the Martinsburg depositional basin. As indicated in the foregoing discussion large dolomite blocks are positioned at different stratigraphic levels. Nowhere can it be conclusively demonstrated that one slide block stratigraphically overlies another, but rather these appear positioned at different stratigraphic levels approximately parallel to the strike of the Martinsburg outcrop belt. As to whether slide emplacement occurred as different events at different time intervals, or as one event over a closely spaced time interval will probably never be conclusively demonstrated. Reasons for this are variations in magnitude of the slides, complex facies relationships between Bushkill and Ramseyburg Members, and variation in lithofacies patterns within the Ramseyburg. Also, lack of adequate biostratigraphic indicators make determination difficult.

Submarine sliding, slumping and emplacement of the Allentown, Rickenback, and gneiss blocks occurred prior to gravity tectonic nappe development and later shearing and thrusting through the nappe core as discussed by Drake (1969). The later thrusting and shearing through the nappe core emplaced Precambrian gneiss onto Lower Paleozoic carbonates to the south of the study area (Drake, 1969).

The previous discussion considers small blocks of quartzo-feldspathic gneiss emplaced within the Martinsburg basin by submarine sliding. It should be pointed out, however, that the physical evidence for such a conclusion is poor. The conclusion is based upon the proximal location of the gneiss blocks to areas of slumped Martinsburg and slide blocks of Allentown Dolomite (figure 1). Slumped Martinsburg occurs stratigraphically below and above the gneiss blocks, however, contacts demonstrating emplacement by submarine sliding are lacking. Also, it cannot be demonstrated that submarine channels actually cut into Precambrian basement or that Precambrian basement was exposed on the slopes of the Martinsburg basin. An alternative origin for the gneiss blocks is that they were tectonically emplaced during thrusting through the nappe core. The gneiss blocks then would overlie the

Martinsburg Formation and would be remanents or outliers of a more extensive Precambrian thrust sheet.

Drake (1969) summarizes the present knowledge of nappe structures in eastern Pennsylvania and western New Jersey. He presumes the Martinsburg and older rocks to be part of a large Precambrian cored nappe (Musconetcong Nappe), with the Martinsburg on the crest and brow of the structure. The Allentown and Rickenback Dolomite allochthons, here interpreted as large submarine slide blocks, are also presumed to be on the crest and brow of the nappe.

This suggests at least two episodes of allochthon emplacement. The first occurred by submarine sliding, the second by gravity tectonic emplacement of the Musconetcong Nappe, and later shearing and thrusting through the nappe core. Zen (1967, 1968, 1972a,b), Bird (1969), Bird and Dewey (1970) have produced similar evidence for two episodes of allochthon emplacement in western New England.

SEDIMENTOLOGY

The sedimentology is presented as a bipartite framework of (1) the depositional environments and (2) the origin and evolution of the Martinsburg depositional trough. Discussion of depositional environments is restricted to the Jacksonburg Limestone and Martinsburg Formation. Integrated summaries of depositional environments which consolidate current ideas and reinterpret the origin and evolution of the Martinsburg basin in New Jersey and Pennsylvania are discussed in the second section.

The Jacksonburg Limestone, though generally thin, represents a spectrum of depositional environments critical to the understanding of Martinsburg sedimentation. Deposition of grainstone, packstone, wackestone, mudstone and conglomerate occurred on a carbonate shelf, slope and submarine valley environments whereas graywackes, claystones and submarine slides of the Martinsburg Formation occurred in an association of non-carbonate base-of-slope and basin environments. Figure 6 diagramatically shows the interpreted depositional setting of the Jacksonburg Limestone and Martinsburg Formation.

DEPOSITIONAL ENVIRONMENTS

Carbonate Shelf - Slope

The carbonate shelf environment is characterized by medium to thick massive beds of relatively clean, sand size skeletal grainstone, packstone and minor detrital grainstone and packstone. More skeletal debris is present than in succeeding environments. Faunal abundance and diversity is usually high. Major taxa are listed in table 1. Oolites, algal and algal coated grains are not present. Differential winnowing has abraded and reworked skeletal grains and has variably removed fines.

This environment is local, being developed best in southwestern sections, and not recognized in northeastern sections. This suggests a regional, or perhaps local variation in paleogeography, paleosubmarine topography and depositional slope. It cannot be demonstrated presently that lithologies interpreted as carbonate shelf are horizontal equivalents to carbonate slope, nor can a transition between the two environments be demonstrated. Alternatively the lithologies described here may be part of the carbonate slope, having originated in a neritic shelf and subsequently transported over the shelf edge onto the basin

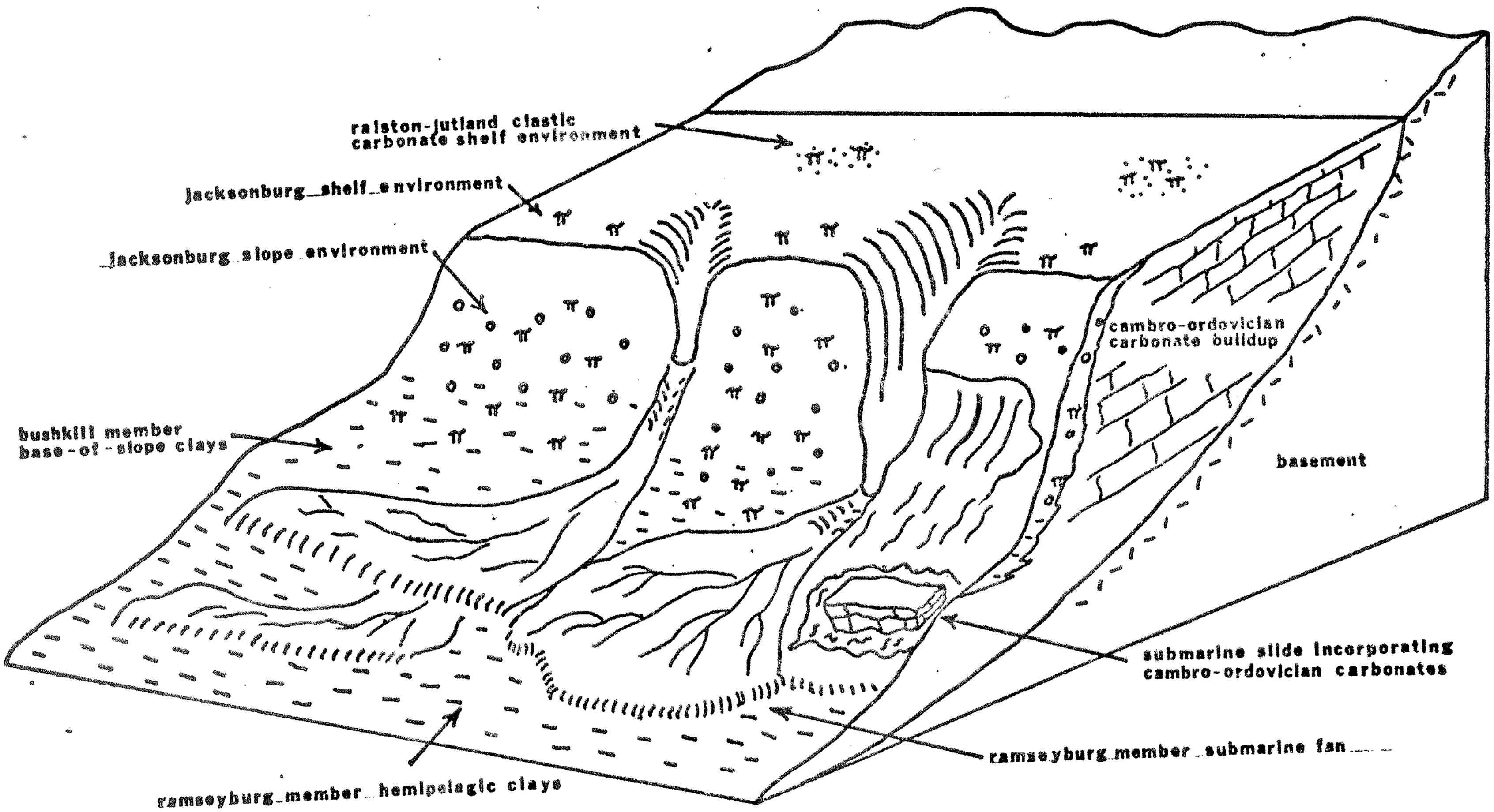

Figure 6 - Block diagram illustrating Jacksonburg Limestone and Martinsburg Formation sedimentation - see text for discussion. Not to scale.

CRITERIA / ENVIRONMENT	LITHOLOGY	COMPOSITION				BEDDING THICKNESSES		SEDIMENTARY STRUCTURES		FAUNA	MECHANISM OF TRANSPORT
		Grain Size	Matrix	Nature Detrital Grains	Percent Detrital Grains	Maximum	Average	Bouma Sequence	Comments		
shelf	skeletal grainstone and pack-stone	sand to pebble	calcite	skeletal	30-80%	2 m +	30-45cm	n.a. (not applicable)	none, beds massive	abundant brachiopods, ectoprocts, pelmatozoans, rugose corals mollusks and trilobites.	traction currents
upper slope	carbonate wackestones	silt to sand	calcite with minor chlorite quarts	terrige-nous, do-lomite, rare skeletal	40-70%	1 m +	30-75cm	n.a.	massive, nodular struc-tures uncommon	uncommon to rare bra-chiopods	mass flow (grain or debris flow)
	pebbly wacke-stones	pebble	carbo-nate silt & sand	dolomite pebbles, terri-genous	15-80%	2 m +	1 m +	n.a.	massive	pelmato-zoans, ectoprocts, rugose corals.	
	carbonate mudstone	clay	calcite chlorite quartz	terri-genous, skeletal	5%	15cm	1cm-5cm	n.a.	well lami-nated	brachio-pods pelmatozoan debris uncommon	suspension
Subma-rine Canyon	conglo-merate	pebble to boulder	silt to coarse sand	dolomite, chert rare skeletal	60-75%	12 m	8-10 m	n.a.	massive, no fabric or imbrication	rare brachio-pods, pelmato-zoans, corals	mass flow

Table 1 - Features characteristic of the shelf and slope environment of the Jacksonburg Limestone, northern New Jersey.

slope.

The carbonate slope is characterized by wackestones, pebbly wackestone and minor calcareous mudstone deposited below storm wave base. Wackestones contain from 40% to 70% recrystallized skeletal debris and sand to silt size allochems of probable skeletal debris. Terrigenous grains comprise less than five percent of the rock. Faunas are diverse and similar to those of the shelf. Faunal abundances are extremely variable and much less than the shelf environment.

X-ray diffractometer patterns of wackestone indicate calcite, quartz and chlorite to be the major constituents. Beds are generally homogenous, massive to weakly graded and range from 0.1 to more than 2 meters thick.

Pebbly wackestones are characterized by ellipsoidal to sub-spherical, usually well rounded dolomite pebbles, presumably derived from the Beekmantown Group. Pebble abundance is highly variable and ranges from several pebbles per bed to pebble conglomerate. Pebbles were presumably derived from exposures in a channel, upslope or shelf edge environment. Pebbly wackestones occur at different stratigraphic levels through out the formation, but are mostly located proximal to cobble and boulder conglomerates. Pebbly wackestones of the Jacksonburg Limestone are interpreted as carbonate equivalents of pebbly mudstones as described by Crowell (1957), Stanley (1969) and Stanley and Unrug (1972). General agreement currently exists that pebbly mudstone deposits are initiated by gravity-driven subaqueous debris or grain flows. Middleton and Hampton (1973), Hampton (1972), Andreson and Bjerrum (1967), Stanley and Unrug (1972) and Walker and Mutti (1973) consider pebbly mudstone a key indicator of a slope environment.

Carbonate mudstones of the Jacksonburg Limestone are considered downslope, base-of-slope or basin margin accumulations. Physical stratigraphy indicates they have locally veneered Beekmantown dolomites or Jacksonburg wackestone or pebbly wackestone. Locally they grade or interfinger into the non-carbonate Bushkill claystone.

Submarine Channel

An excellent summary listing criteria for interpretation of ancient deep sea channel deposits is given by Whitaker (1974). Applicable criteria for interpretation of Jacksonburg submarine channels as listed by Whitaker include comparable size, geometry, position relative to shallower and deeper water deposits and lithology.

Outcrop patterns for this environment of the Jacksonburg Limestone indicate a channel morphology, where channel fill consists of rounded to subangular pebbles, cobbles and boulders of fine to coarsely crystalline laminated Beekmantown dolomite and chert. The conglomerates are clast supported, have a carbonate silt to coarse sand matrix, rare skeletal material and occur in beds from 3 to 15 meters thick (table 1).

The Jacksonburg Limestone conglomerates may be subdivided into two units; (a) those lacking recognizable fabric, imbrication or bedding and (b) those with slight normal grading overlain by crude parallel lamination or incipient wackestone flaser beds 1 to 4 cm thick and up to 1 meter in length, and irregular internal erosion surfaces. A northerly directed paleoslope is indicated by decreases in average clast size and angularity in that direction. Distance of transport for the boulders need not have been large. Direct channeling and reworking of the paleosolution breccia (Marckewicz, 1974) of the Epler Formation (figure 2) indicates in situ formation for at least some of the channel fill, whereas overall outcrop distribution of cobble and boulder conglomerates suggests a minimum horizontal transport of 2 km. Submarine channel width near Hope, New Jersey appears to be approximately 3 km. Downcutting and channel fill within the Epler Formation is interpreted as a submarine canyon whereas channel conglomerates interbedded with dolomitic claystone of the Bushkill is interpreted as upper fan valley. Fan valley fill is inferred to be continuous with outcrops interpreted as submarine canyon.

Base-of-Slope

Martinsburg base-of-slope environment is characterized chiefly by deposition of autochthonous Bushkill claystone and allochthonous submarine slides of Allentown and Rickenback Dolomite quartzo-feldspathic gneiss and slumped claystones and graywackes (table 2). Locally submarine channels of the Jacksonburg have dissected the base-of-slope or rise apron. Levee deposits of the Bushkill and upper submarine fan deposits of the Ramseyburg are present. This environment overlaps into the basin where lithofacies of middle and lower submarine fans and hemipelagites dominate.

Autochthonous base-of-slope deposits are interpreted as dark to medium gray very fine grained, thin to medium massive beds of claystone slate, with uncommon very thin laminae of carbonaceous and silt size detritus. Secondary pyrite locally accompanies the lamina.

In environments analogous to the one proposed for the Martinsburg base-of-slope submarine slides and slumps are common.

CRITERIA / ENVIRONMENT	LITHOLOGY	COMPOSITION				BEDDING THICKNESSES		SEDIMENTARY STRUCTURES		FAUNA	MECHANISM OF TRANSPORT
		Grain Size	Matrix	Nature Detrital Grains	Percent Detrital Grains	Maximum	Average	Bouma Sequence	Comments		
upper fan valley	conglomerate	pebble to boulder	silk to coarse sand	dolomite, chert, rare skeletal	60-75%	12 m	5-8 m	a.b.		rare brachiopods, pelmatozoans, ectoprocts and corals	mass flow/ turbidity current
levee	dolomitic claystone	clay	dolomitic minor calcite	dolomite	5%	1 cm	0.5 cm	n.a.	abundant thin laminations		suspension
	wackestone	silt to coarse sand	calcite dolomite	dolomite, skeletal	75%	15 cm	7 cm	a b; a b c		pelmatozoans, ectoprocts and minor brachiopods	turbidity flow
autochthonous base-of-slope	claystone	clay	2M mica, chlorite quartz	terrigenous (quartz)	5%	40 cm	10 cm	n.a.	thin laminae common. Laminae composed of carbonaceous material and detrital silt terrigenous grains	graptolites rare	suspension
allochthonous base-of-slope	claystone	clay	2M mica chlorite quartz	terrigenous (quartz)	5%	30 cm	20 cm	n.a.	abundant sedimentary folds and slide planes		gravity generated submarine slides and slumps
	graywackes	fn to v fn sand	chlorite 2M mica calcite	terrigenous	60-77%	20 cm	10 cm	a b c; b c; c	abundant sedimentary folds and slide planes		
	Cambro-Ordovician dolomite & limestone	coarse sand to clay	calcite dolomite	minor quartz, feldspar	variable less than 10%	thin to thick	thin to thick	n.a.	algal stromatolites in dolomite allochthons. Rare ostracods in thin section		

Table 2 - Features characteristic of the base-of-slope environment of the Jacksonburg Limestone and Martinsburg Formation, norther New Jersey.

Resedimentation of shallow water limestones as debris flows or submarine slides and incorporation in basinal carbonates or pelites are considered by Mountjoy and others (1972) as worldwide indicators of reef complexes, carbonate banks or shelf margins. Mountjoy and others consider bedded megabreccias incorporated in marine shales or argillaceous limestones criteria for identifying the carbonate bank or shelf margin environment. Such criteria has been successfully applied in identifying this environment in the Pennsylvanian and Permian of west Texas (Rigby, 1958; Ray and Stehli, 1962; Newell and others, 1953; and Tyrrell, 1969), the Jurassic Alpine of Europe (Garrison and Fisher, 1969), the Devonian of western Canada (Mountjoy and others 1972; Hopkins 1971) the Cretaceous of Mexico (Enos, 1974) the contemporary Bahama Platform (Andrews and others, 1970) and the Cambro-Ordovician of the Appalachians (Rodgers, 1968, 1970; Palmer, 1973; Taylor, 1973; and Swett and Smit, 1972).

The submarine slides discussed in the previous section are interpreted to have been deposited in the lower slope, base-of-slope environment. Because of the direct involvement and original shallow water deposition of the Allentown Dolomite and the previous summary, the slope is interpreted as the edge of a carbonate bank. This type of margin is consistent with current thinking for the Cambro-Ordovician continental margin of the Appalachians from Alabama to New Foundland (Rodgers, 1968, 1970). The major difference is that the carbonate bank appears west facing rather than east facing as described by previous authors. This recognition suggest an off shore bank for this part of the Appalachians. This will be discussed in greater detail in the following section.

The slides with incorporated blocks of Allentown and Rickenback Dolomite near Hope, New Jersey and Newton, New Jersey are situated proximal to submarine channel lithofacies of the Jacksonburg Limestone. These two slides have produced slumping and sedimentary folding of Bushkill claystones and Ramseyburg graywackes. The conclusion that these slides were genetically associated with submarine channels is tempting. The slides near Johnsonburg, New Jersey and Greendell, New Jersey do not appear to be associated with submarine channel lithologies. Slumping and sedimentary folding of the Martinsburg lithofacies present at this slide area is minimal compared to those near Hope, New Jersey and Newton, New Jersey. The Johnsonburg - Greendell slides may have been generated as rock falls or slides on a relatively steep margin and need not have been associated with submarine channels.

Submarine Fans

Lithofacies of the Martinsburg interpreted as submarine fan deposits consist of graywacke cycles summarized in the preceding section. Martinsburg fan deposits are small by comparison to contemporary fans. This is considered to be a reflection of the relatively narrow restricted basin in which they were deposited.

Fan deposits are recognized primarily by lenticular, overlapping graywacke cycles with claystone interbeds, lack of regional stratigraphic correlation, and rapid lateral changes in bedding thicknesses and Bouma sequences. Sedimentary structures and other physical characteristics are summarized in table 3. Sequences recognized within the Martinsburg generally conform to the characteristics of upper, middle and lower or interchannel fan deposits. Actual assignment to a subenvironment is problematical and interpretation is essentially congruent with the base-of-slope and basin environment.

The upper fan environment consists of previously described submarine channel fill of the Jacksonburg, attributed to fan valley origin and fan valley levees. Levee deposits are characterized by very thin, parallel laminated detrital dolomitic silt and claystone and thin bioclastic limestone of the Bushkill. These are proximal to Jacksonburg channel conglomerates. Bioclastic limestone beds are composed of silt to sand size skeletal and detrital dolomite grains. Typical structures include the Bouma a and ab interval. Sole markings are uncommon. These beds were probably derived and deposited by turbidity currents flowing and overspilling from the upper fan valley. Levee deposits grade laterally into thicker bedded non-carbonate Bushkill claystone of the base-of-slope environment.

Overbank turbidite sands are rare indicating the associated channels were probably of sufficient depth to contain the volume of material brought downslope or that overbank flows were of sufficient competence that minimal deposition occurred. This conclusion tends to be supported in a contemporary levee environment as described by Shepard and others (1969) and Shepard and Einsley (1962) and Piper (1970) who in an extensive survey of natural levees of the La Jolla fan valley noted that textural layer variations appear to be functions of channel wall height and position relative to the fan valley. Those levees lacking coarse sand layers were associated with high (55 m) valley wall heights whereas thicker sand layers occur along the outer part of the fan valley.

Middle fan deposits are characterized by medium to thick beds

CRITERIA / ENVIRONMENT	LITHOLOGY	Grain Size	COMPOSITION: Matrix	COMPOSITION: Nature Detrital Grains	COMPOSITION: Percent Detrital Grains	BEDDING THICKNESSES: Maximum	BEDDING THICKNESSES: Average	SEDIMENTARY STRUCTURES: Bouma Sequence	SEDIMENTARY STRUCTURES: Comments	FAUNA	MECHANISM OF TRANSPORT
Middle Fan	gray-wackes	very fine sand	silt, terri-genous calcite 2M mica, chlorite	terri-genous quartz and plu-tonic rock	55-80%	2 m+	40 cm	abcde; ade; abde; acde; bcde; bde	e interval thin rela-tive to whole of bed. Trough crossbeds in c inter-val to 45cm thick	rare diminu-tive faunas, graptolites	turbidity current
Lower Fan	gray-wackes	silt v fn sand	same as Middle Fan	terri-genous	30-65%	50 cm	15-20cm	bcde; cde	a interval markedly absent	none found	distal turbidity or trac-tion current
Lower Fan (Fan Fringe Fan Inter-channel)	gray-wackes	silt v fn sand	same as Middle Fan	terri-genous	approxi-mate same as Lower Fan	1 m	10-15cm	cde	de inter-val thin undula-tory, pinches and swells	none found	traction or distal fringe of turbidity current
Hemipe-lagic Sediments	claystone	clay	same as thonous	autoch-thonous	3%	15 cm	4-8 cm	n.a.	(40) to 100+ carbo-naceous and silt laminae per meter	none found	suspension
	quartzose siltstone or gray-wackes	silt	same as thonous		60-95%	2 cm	1 cm	a, ab	sharp bases and tops, minor load-ing into underlying clays	none found	turbidity or contour currents

Table 3 - Features characteristic of the Basin Environment of Martinsburg Formation, northern New Jersey

of firmly indurated very fine to medium grained sand commonly having calcite cement and matrix less than 35%. Lower bedding surfaces are sharp, either loaded into underlying claystones, and showing flute or groove casts, or planar and even with parting lineation. Ripped up shale clasts are locally present in the basal portion of the bed. Complete Bouma sequences are present, but on the whole are uncommon. Partial Bouma sequences consisting of ae, abe, ace, be, or bce are abundant. The a intervals are usually poorly graded or massive. Actual grading is from medium or fine grained sand to very fine grained sand or silt. The c interval consists of ripple cross lamination, cross bedding and convolute bedding. Climbing ripples are rare. The thickest beds may have trough cross bed set thickness to 45 cm. and widths to 10 m. Single convoluted beds approach 20 cm. The e interval is thin not exceeding 10 cm.

Lower fan deposits are characteristically thinner bedded, grain sizes smaller and matrix content higher than middle fan graywackes (table 3). A bcde Bouma sequence is almost universal. The Bouma a interval is markedly absent. The c interval consists of ripple cross lamination, climbing ripples and small convolutions. Ripple foresets are commonly oversteepened.

The final unit of fan graywackes occurs in thin to thick beds of silt and very fine grained sand. These units are characterized by the Bouma cde sequence. The c interval has abundant convolute, oversteepened ripple cross lamination, and climbing ripple lamination. The de interval is usually very thin, commonly pinches and swells, and is not persistent for distances of more than a few meters. Precise interpretation is problematical, however, they occur stratigraphically below and lateral to graywackes of upper, middle and lower fan deposits. Deposition may have occurred in a lower fan, inter-channel or levee environment.

Hemipelagic Sediments

This environment consists of laminated claystones, and forms the bulk of the Martinsburg lithofacies. The claystones are typically dark gray to dark medium gray claystone with abundant varve-like black parallel laminations. The black laminae are composed of carbonaceous material, silt and very find grained sand. Maximum lamination thickness is 1.5 cm. Laminae are abundant, ranging from 30 to more than 100 per meter. Non-carbonaceous claystone interbeds are massive, contain less than 3% detrital silt and sand, and range from 1 to 8 cm thick. These units lack sedimentary structures. Presumably the material was deposited from suspension.

Within this environment are thin discontinuous beds of well sorted quartz silt and minor graywacke. These beds pinch and swell and are rarely continuous for more than three meters. Bouma sequences are commonly a massive or graded a interval followed rarely by b, c, or bc intervals. The units are characterized by sharp bases and tops. Maximum thickness is 2.5 cm. These units are interpreted as possible contourites or distal turbidites.

ORIGIN AND DEVELOPMENT OF THE MARTINSBURG BASIN

This portion of the paper interprets the development of the Martinsburg basin and the changes in depositional environments through time. This involves considerable synthesis and interpretation of stratigraphic and structural data from literature sources, most of which has been diagramatically incorporated in figure 7.

Pre-Middle Ordovician sedimentation in the central and northern Appalachians has been generally described as a southeast thickening wedge of miogeosynclinal Late Precambrian and Cambrian quartz sandstones, overlain by Cambro - Ordovician dolomites and limestone (Bird and Dewey, 1970; Colton, 1970; Dietz and Holden, 1967; Rodgers, 1968). Dewey considers this framework to have developed during spreading of a proto - Atlantic Ocean from Late Precambrian to Lower Ordovician time.

The sedimentological evidence presented in the preceding sections suggests that in the vicinity of northern New Jersey and possibly southeastern New York and eastern Pennsylvania an offshore carbonate bank existed, producing a long standing starved basin (Martinsburg basin). In northern New Jersey carbonate bank deposition commenced with the Lower Cambrian Leithsville Formation and continued into upper Lower Ordovician, with deposition of the Beekmantown Group (figure 2).

In northern New Jersey and eastern Pennsylvania lithofacies distribution of the Jacksonburg Limestone and Martinsburg Formation suggest that these two formations represent progressive and continuous infilling of a starved basin from middle Trenton to Maysville time. Middle Ordovician basin sedimentation is characterized by rapid facies change across a bank margin. The Jacksonburg is a thin sequence of slope lithofacies unconformable on the relatively steep carbonate bank of the eastern basin margin.

Parallel to this margin, at or near the base-of-slope, large scale submarine slides have involved resedimentation of Cambro-Ordovician dolomite and limestone. The dolomite and limestone blocks discussed in preceding sections exhibit criteria which indicate origi-

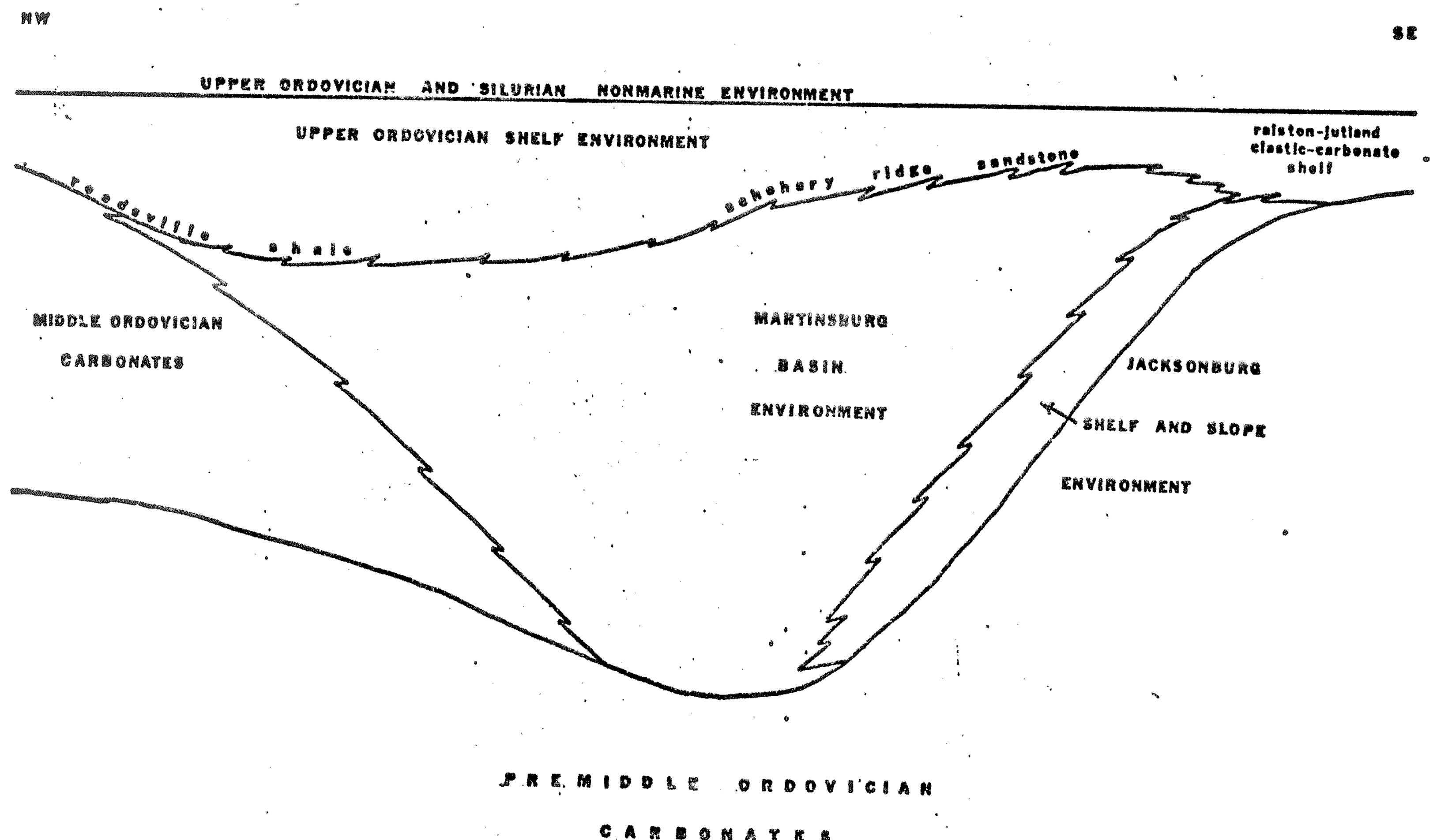

Figure 7 - Diagramatic representation of sedimentary environments within Middle and Upper Ordovician time in the Central Appalachians

nal deposition in shallow water. The occurrence of dolomite and limestone blocks within Martinsburg lithofacies is geographically widespread. Miller (1937a) and Aldridge (1967) have identified Allentown Dolomite enclosed within the Martinsburg in eastern Pennsylvania. Dyson (1967) reports calcareous sandstone, grainstone and oolitic grainstone from a middle subdivision of the Martinsburg from west of the Susquehanna River in Pennsylvania. Also, Knopf (1962) demonstrated that blocks of Cambrian and Ordovician limestone are enclosed in Middle Ordovician shales in southeastern New York. Aldridge (1967) considers a pretectonic submarine slide emplacement of the limestone within eastern Pennsylvania. It is probable and consistent within the ideas presented that the dolomite and limestone within the Martinsburg of central Pennsylvania and southeastern New York also originated by submarine slide emplacement. It is suggested that the distribution of large scale bedded dolomite and limestone blocks within the Martinsburg may prove to be indicators of the geographic extent of the offshore carbonate bank.

The western basin margin is not characterized by a steep carbonate bank, but rather by apparently continuous sedimentation and facies changes from Lower Cambrian through Upper Ordovician time (figure 2 & 7). Facies changes suggest an overall westerly migration of sedimentary environments. Lower and Middle Ordovician carbonate shelf deposits were replaced by westerly migrating lower Upper Ordovician Reedsville Shale shelf sediments (Wagner, 1966; Thompson, 1972), and culminated with deposition of the Upper Ordovician molasse of the Bald Eagle Sandstone and Juniata Formation.

To the southeast of the carbonate bank margin in the vicinity of Jutland and Ralston, New Jersey, a relatively thin clastic carbonate facies overlies the Beekmantown Group and locally the Jacksonburg Limestone. F. J. Marckewicz (unpub. data) and Minard (1959) consider characteristic lithologies to be red, green, yellow and brown shales and siltstones, quartz - feldspar conglomerates, glauconitic sandstone and conglomerate, and limestone including oolitic limestone. Conglomerate units contain gneiss and limestone pebbles and are presumed to have been locally derived from exposed Precambrian terrain. Minard estimates the preserved section near Ralston to be approximately 600 meters and F. J. Marckewicz estimates preserved section near Jutland to be 750 meters. These sections are relatively thin compared to the main Martinsburg outcrop belt discussed in this report and by Drake and Epstein (1967). Marckewicz (personal communication) presumes the lithologies at Jutland to have been deposited in a shallow water shelf environment. The lithologies and depositional environments are similar to those reported by Walker (1970) for the Martinsburg in Virginia.

Graptolite faunas from the Jutland sequence indicate both an early and middle Ordovician age. The early Ordovician faunas correlate with the Deepkill Shale (Drake, 1969; U.S.G.S. Research, 1964, p. A-83; and Zen, 1972a) and the Poultney Slate of New York (Pessitorities, and others, 1974). They are reported to overlie younger, Middle Ordovician faunas which tentatively correlate with the Normanskill Formation of New York. The present allochthonous structural position of these faunas has prompted interpretation and correlation with the Taconic allochthon of New York (Drake, 1969, Pessitoritis and others, 1974 and Zen, 1970). Drake (1969) does not consider the origin of the allochthon of the Jutland sequence as a submarine gravity slide because of a lack of flysch lithologies. It is not the object to identify the mode of emplacement. The importance is, that there exists to the southeast of the main Martinsburg outcrop belt a relatively thin sequence of rocks of equivalent age that were deposited within a depositional environment that markedly differs from the depositional environment of the main Martinsburg outcrop belt. From this it can be inferred that a lateral transition of sedimentary environments existed within the early and Middle Ordovician. This transition is envisioned as a change in environment from a carbonate bank to a starved basin. A thin sequence of shelf lithologies was deposited on the remnant Beekmantown carbonate bank. Northwesterly across the bank edge, a thin sequence of slope lithologies, large submarine channels, and a thick package of basin fill sediments including submarine fans and hemipelagic clays reflects the transition to a starved basin.

Martinsburg sedimentation culminated in the Upper Ordovician with deposition of the Reedsville Shale (Eden - Maysville age) shelf environment (Thompson, 1972) in central Pennsylvania and the Schohary Ridge sandstone beds (middle Eden age) of the Martinsburg in eastern Pennsylvania (Platt, 1972). Bretsky (1969) and Willard (1943) consider brachiopod faunas of the Schohary Ridge to represent an inner sublittoral quiet water shelf environment. McBride (1962) considers the Schohary Ridge sandstone beds to have been deposited under shallower water conditions and closer to the course area than other Martinsburg graywackes. In addition to representing a lateral transition from a southeasterly shelf environment of the Jutland sequence northwesterly into a basin environment, the Martinsburg appears to represent basin shallowing through time from middle Trenton deeper water flysch to a

Maysville - Eden shallow water shelf.

DISCUSSION

The origin of the Martinsburg depositional basin as a long standing starved basin adjacent to a build up of shallow water carbonates is an actualistic concept of sedimentary basin origin. Modern and ancient analogs of carbonate bank to basin transitions are common within the literature, and selected examples have previously been cited.

The concept of this type of origin for the Martinsburg depositional basin provides an alternative to the hypothesis of basin origin as expressed by Bird and Dewey (1970) and Dietz and Holden (1974). These authors regard the Middle Ordovician flysch basin of the Taconic region to be the result of sagging of the miogeosyncline. The sagging was allegedly generated in upper Lower Ordovician time by a proto Atlantic plate underthrusting a proto North American plate (Taconic Orogeny).

Lochman (1956) and Rodgers (1968) suggested the possibility of an offshore carbonate buildup in eastern New York and western Vermont. Zen (1961, 1967, 1968, 1972b) has suggested that the sequence considered by Lochman as a probable basinal pelite sequence between two carbonate margins is actually part of the Taconic allochthon. The original depositional site of the pelites was to the east of carbonate deposition and has been transported westerly during the Taconic Orogeny. The present site of the allochthonous sequence is within the Middle Ordovician flysch basin (Martinsburg - Normanskill exogeosyncline). Similarly Rodgers (1968) accepts an allochthonous origin for the pelitic units that surround probable shallow water carbonates.

In the structurally complex terrains of western New England and the north central Appalachians conceptual sedimentologic models need to be generated in order to enhance the knowledge and development of Paleozoic plate motions, the nature and relative position in time and space of Cambro-Ordovician basin margins. A direct consequence of these models would be a more detailed paleogeography encompassing the nature and timing of paleoslope reversal from an easterly paleoslope in Cambrian and Lower Ordovician to a westerly paleoslope in Middle and Upper Ordovician.

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Stephen Garrett Pollock

1946	Born February 25 in West Chester, Pennsylvania.
1964	Graduated from Downingtown Sr. High School, Downingtown, Pennsylvania.
1968	A.B., Bucknell University, Lewisburg, Pennsylvania.
1968-1972	Graduate work in Geology, University of Maine.
1972	M.S. in Geology
1972-1975	Graduate work in Geology, Rutgers University, New Brunswick, New Jersey.
1975	Ph.D. in Geology.