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A petrographic study of the Mauch Chunk-Pottsville transition zone in northeastern Pennsylvania.

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A PETROGRAPHIC STUDY OF THE MAUCH CHUNK-POTTSVILLE TRANSITION ZONE IN NORTHEASTERN PENNSYLVANIA

by

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A Thesis

Presented to the Graduate Committee

of Lehigh University

in Candidacy for the Degree of

Master of Science

in

Geology

Lehigh University

1980

This thesis is accepted and approved in partial fulfillment of the requirements for the degree of Master of Science.

May 9, 1980
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ACKNOWLEDGMENTS

My sincere thanks goes to Dr. J. Donald Ryan of Lehigh University for serving as my advisor and for his invaluable guidance and criticism throughout the entire field, laboratory and writing phases of this project. Great appreciation is extended to Dr. Paul B. Myers of Lehigh University and Dr. Edwin S. Erickson, Jr. of Bethlehem Steel Corp. for their assistance, critical commentary and service on my thesis committee.

I am indebted to fellow graduate student Gary G. Lash for his expert assistance in the field and for his help and very informative criticism during the preparation of the manuscripts. I thoroughly enjoyed the many enlightening discussions I had with Gary.

The writer thanks Dr. Hayden N. Pritchard of the Biology Department at Lehigh University for his kind permission and instruction in the use of his photomicroscopy equipment.

The writer wishes to express his thanks and appreciation to his parents Dr. and Mrs. Laurence C. Griesemer for their financial support and patience throughout the course of this study.

A very special thanks and appreciation is extended to my dear friend, Deanna Borchers, for her diligent typing of the preliminary manuscripts, but most of all, for her patience, encouragement and devotion throughout the course of this project.

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ABSTRACT

The Mauch Chunk-Pottsville transition zone in northeastern Pennsylvania consists of alternating, probably intertonguing beds of Pennsylvanian Pottsville type gray sandstones and conglomerates, and Mississippian Mauch Chunk type red shales. Placement of the Mauch Chunk-Pottsville contact remains arbitrary.

The sandstone units in the transition zone are petrographically similar to the immediately superjacent Pottsville sandstones and dissimilar to the subjacent Mauch Chunk sandstones; Pottsville and transition zone sandstones are dominantly quartzose conglomerates and gray massive coarse-grained lithic arenites. They consist of a quartz-rich framework and abundant pseudomatrix formed from crushed and deformed metasedimentary and sedimentary rock fragments which were originally part of the framework. Mauch Chunk sandstones also have a quartz-rich framework and a pseudomatrix, but they are red, finer-grained, cross-bedded, and, in some cases, laminated. Unlike the gray transition zone sandstones, plagioclase feldspar

and calcite commonly are present in the Mauch Chunk sandstones.

Shales in the transition zone are comparable to Mauch Chunk shales; both are red and in both, the clays are illite and chlorite. Pottsville shales are gray and contain no chlorite.

Transition zone sediments reflect an episodic change from a relatively high energy sedimentary regime to one of lower energy. The depositional model suggested is that coarse sands and gravels from the Pottsville alluvial plain prograded onto flood plain deposits of the older Mauch Chunk deltaic complex. The Pottsville alluvial sandstones occupy erosional scours and channels in Mauch Chunk muds deposited under relatively quiescent conditions. Renewed episodic uplift in the source area or further downwarping in the depositional basin may explain such a change in environmental conditions.

Textural and compositional evidence indicate a southeasterly source consisting primarily of meta-sedimentary and sedimentary rocks with minor amounts of intercalated igneous and hydrothermal material.

This interpretation is based on: 1) grain-size distribution, 2) comparison of the composition of the transition zone rocks with other lithic sandstones from presumably known metasedimentary type sources, 3) relative proportions of coarse- and fine-grained polycrystalline quartz, and of undulatory and nonundulatory quartz.

Diagenetic features indicate that the transition rocks have reached a maximum burial depth of over 1000 meters. This is compatible with depth of burial estimates based on the aggregate thickness of the overlying Pottsville and Llewellyn Formations.

INTRODUCTION

Problem and Objectives

The Mauch Chunk Formation in northeastern Pennsylvania is comprised of a series of dominantly red sandstones, siltstones, and shales of Mississippian and Lower Pennsylvanian (?) age (Wood, Trexler, Arndt, 1962). It is overlain by the Pennsylvanian Pottsville Formation consisting of gray conglomerates, conglomeratic sandstones, and sandstones interbedded with siltstones, shales, and anthracite. The Mauch Chunk-Pottsville contact in eastern Pennsylvania is conformable (Wood et al, 1956), but disconformable in the northern and western part of the state (Hoque, 1968; Meckel, 1970).

The contact in eastern Pennsylvania is transitional. The transition zone is composed of alternating beds of Mauch Chunk type red shales and Pottsville type gray sandstones and conglomerates and fossils are rare. Therefore, assignment of the exact position of the Mauch Chunk-Pottsville contact has been largely arbitrary. The confusion, especially in early studies, is exemplified by Smith (1895), who stated that the placement of the Mauch Chunk-Pottsville contact is a matter of personal preference. White (1900) made the first assignment of the stratigraphic position of the transition zone and stated that all rocks below and including the uppermost red bed are to be considered part of the Mauch Chunk Formation. Other workers (Barrell, 1907; Wood et al, 1956; Wood et al, 1962) have followed the precedent of White and have arbitrarily placed the contact at the top of the uppermost red bed. Klemic (1962) and Epstein et al (1974) stated that placement of the contact at the top of the highest red bed was an aid in mapping. Dyson (1954), Klemic et al (1954), Montgomery (1954), McCauley (1957), however, included the transition zone in the lower part of the Pottsville Formation. Gault et al (1957) stated that the first appearance of a new lithology indicated new conditions of deposition and thus considered the transition a lower Pottsville unit. Current feeling by both the Pennsylvania Geological Survey and the United States Geological Survey is that the transition zone is arbitrarily placed at the top of the

Mauch Chunk Formation for mapping purposes.

The transition zone has been considered by some investigators (Wood et al, 1962; Meckel, 1967; Meckel, 1970; Edmunds et al, 1979) as a zone of interbedded upper Mauch Chunk and lower Pottsville rocks. Wood, Trexler, and Arndt (1962) by stratigraphic and mapping studies concluded that the Mauch Chunk-Pottsville contact does have an intertonguing relationship and that the Pottsville laterally replaces the Mauch Chunk, which causes the contact to rise above the Mississippian-Pennsylvanian time boundary. Meckel (1970) stated that the transition zone crosses time lines due to the general transgressive and regressive nature of Paleozoic deposition in the central Appalachians and that the red shales and gray sandstones are laterally equivalent facies. A petrographic examination of the transition zone rocks might aid in the confirmation of this interpretation.

The transition zone represents an unusual juxtaposition of two contrasting environments of deposition. Together, the Mauch Chunk and Pottsville depositional model has only been generally described as a fluvial deltaic system overrun by coarse sediments on an alluvial plain (Edmunds et al, 1979). Such a general model fails to describe the depositional framework that enabled the rapid alteration of two such contrasting environments to occur; therefore, the creation of a scaled-down model representing times of transition zone deposition exclusively might aid in the understanding of the dynamics of transition deposition.

The objectives of this project are:

1) To determine if sandstones in the transition zone are petrographically similar or dissimilar to sandstones in the Pottsville and Mauch Chunk Formations; this might assist in the definition of a Mauch Chunk-Pottsville contact.

2) To produce, from already published ideas regarding the Mauch Chunk-Pottsville environments of deposition and from field observations in the measured sections, a model for the transition zone's environment

of deposition.

3) To learn about the compositional nature of the source material from detailed petrographic studies of the constituents present in the transition sandstones and conglomerates.

4) To make inferences regarding the post-depositional conditions of temperature and depth of burial imposed on the transition rocks by studying diagenetic evidence in thin section.

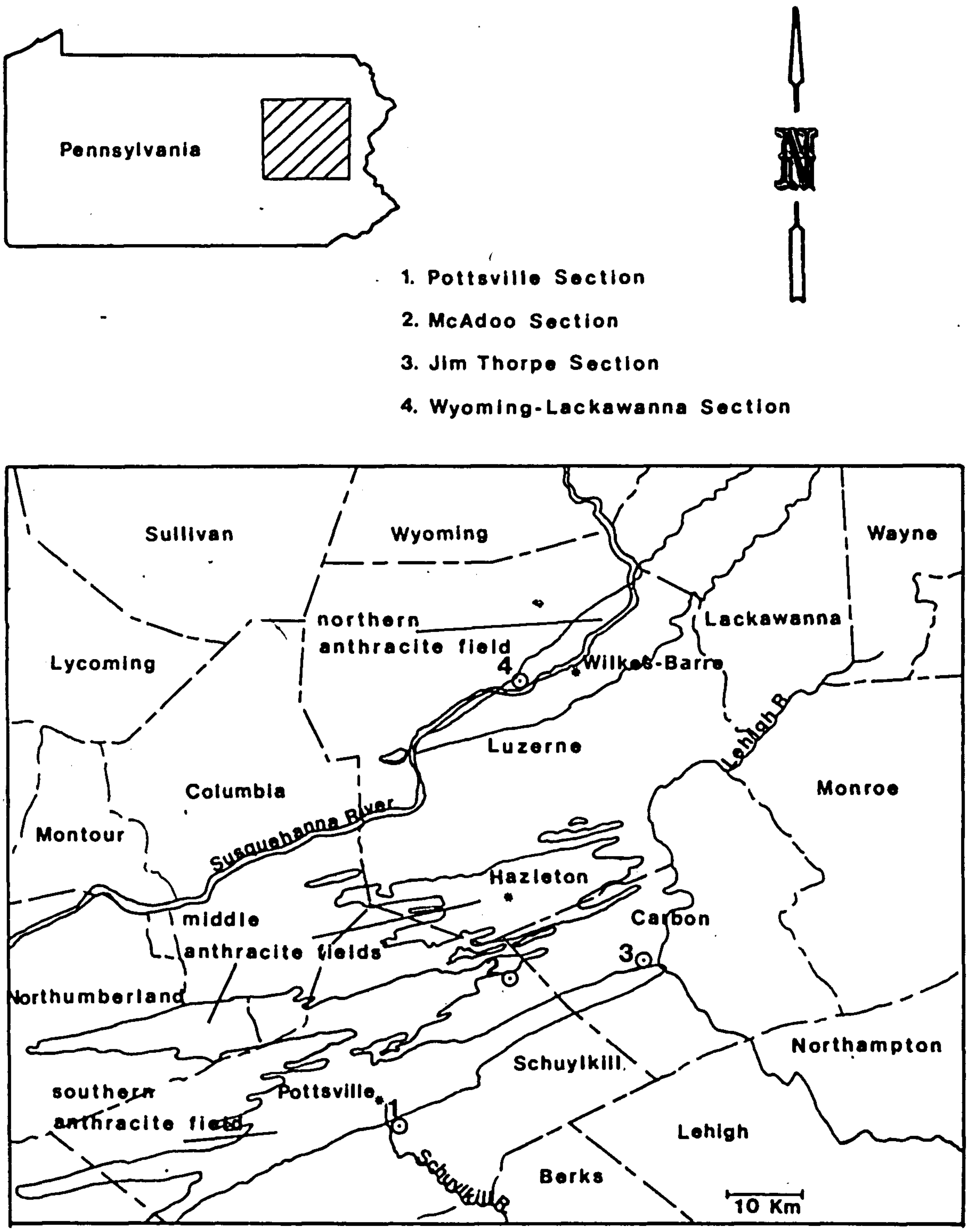
Location and Geological Setting

The Mauch Chunk and Pottsville rocks outcrop in northeastern Pennsylvania along the entire margin of the southern and middle anthracite fields, and only on the southwestern margin of the northern anthracite field. The type sections for the Mauch Chunk and Pottsville Formations are at Jim Thorpe, Pennsylvania (Lesley et al, 1895) and Pottsville, Pennsylvania (Wood et al, 1956) respectively.

Samples for study were collected from four measured full or partial stratigraphic sections of the Mauch Chunk-Pottsville transition situated along the margins of the southern, middle, and northern anthracite fields in northeast Pennsylvania (Figure 1). These are: 1) the Pottsville and 2) McAdoo sections, both located in Schuylkill County, 1.6 kilometers south of Pottsville, Pennsylvania and 9.6 kilometers southwest of Hazelton, Pennsylvania, respectively; 3) the Jim Thorpe section, 1.5 kilometers northwest of Jim Thorpe, Pennsylvania in Carbon County and, 4) the Wyoming-Lackawanna section located 2.8 kilometers north of Nanticoke, Pennsylvania.

The Mauch Chunk and Pottsville Formations are part of the upper Paleozoic continental clastic sediment sequence in the folded Appalachian Mountain section of the Valley and Ridge Province of Pennsylvania. King (1977) subdivides the Paleozoic columnar section and the Pennsylvania Valley and Ridge Province into four groups, each group representing a generalized lithofacies. The column begins with thin basal marine clastics of Lower Cambrian age resting

Figure 1 - Location map of the study area and the four measured sections.



Pennsylvania
N
1. Pottsville Section
2. McAdoo Section
3. Jim Thorpe Section
4. Wyoming-Lackawanna Section
Sullivan
Wyoming
Wayne
Lackawanna
Lycoming
northern
anthracite field
Wilkes-Barre
Luzerne
Lehigh R.
Columbia
Montour
Monroe
Susquehanna River
Hazleton
middle
anthracite fields
Carbon
Northumberland
Northampton
Schuylkill
southern
anthracite field
Pottsville
Lehigh
Schuylkill R.
Berks
10 Km

unconformably on the Precambrian basement. These are succeeded by Cambro-Ordovician marine carbonates, which in turn are followed by a sequence of dominantly marine clastics ranging in age from Middle Ordovician to Middle Devonian. The uppermost group consists of the continental clastics ranging in age from Upper Devonian to Pennsylvanian.

According to Edmunds et al (1979), the Mauch Chunk Formation represents a Late Mississippian-Early Pennsylvanian north-westward prograding deltaic complex. Progradation of Mauch Chunk sediments continued and most likely encroached across the northwest uplifted areas for some unknown distance until continued uplifting caused erosion of the marginal Mauch Chunk deposits (Edmunds et al, 1979). At the start of Pennsylvanian time, coarse clastic material of the Pottsville overran the Mauch Chunk from the southeast until an alluvian blanket covered all but the northwest corner of Pennsylvania by Early-Middle Pennsylvanian time.

PREVIOUS WORK

Mauch Chunk Formation (Including the Transition Zone)

In his report on the geology of Pennsylvania, Rodgers (1858) used the term "Umbral Red Shale" to designate the red carboniferous shales and siltstones later named by Lesley (1876) as "Mauch Chunk Red Shale". Rodgers (1858) noticed numerous mudcracks and rain imprints in the shales and attributed their origin to a shallow marine environment. One of the earliest extensive lithologic and stratigraphic reports of the Mauch Chunk Formation in Pennsylvania was given in 1895 by Lesley et al. They based their work on measured sections near Jim Thorpe, in the northern anthracite region, in northwest Pennsylvania, at Allegheny Mountain, and in the Westmoreland and Fayette County district. Grabau (1906) was the first author to associate the Mauch Chunk with nonmarine deposition. He claimed that fluvial deposition, including flood plain and nonmarine fan formation, dominated and based his conclusion on the presence of ripple marks, mudcracks, rain prints, and vertebrate footprints, as well as on the lack of marine fossils. Barrell (1907) agreed with Grabau's origin and added additional supportive evidence by noting the general coarsening of sand towards the eastern source. Barrell's description included measured sections and fossil studies.

Recent work on the Mauch Chunk Formation includes an extensive sedimentalogical and paleo-current study by Hoque (1968). He gives an excellent lithologic, petrographic, sedimentalogic, sediment dispersal, and paleocurrent description of the Mauch Chunk in central and southwestern Pennsylvania and confirms the fluvial deltaic origin. Epstein et al (1974) in their mapping work of the Lehighton and Palmerton quadrangles describe the lithology of the Mauch Chunk Formation at the type section near Jim Thorpe as a 1700 foot thick sequence of red siltstones and sandstones.

Although no similar petrographic study has been published exclusively on the sandstones in the Mauch Chunk-Pottsville transition, general descriptions of these rocks have been included in various regional studies and economic geology reports on the area.

The transition zone was first described by Smith (1895), who included it in his description of the rocks of the anthracite regions of Pennsylvania. Smith noted that the Mauch Chunk-Pottsville transition was a zone of red shales decreasing in thickness and eventually disappearing within layers of gray sandstones and conglomerates. Lithologic descriptions and sketches of the transition zone were given by White (1900) in his report of fossil floras in the Pottsville Formation. More recently, the transition rocks have been included in reports discussing the uranium occurrences found in some of the transition conglomerates. Descriptions of gross lithologies within the transition zone at Jim Thorpe have been made by Dyson (1954), Klemic and Baker (1954), Klemic (1962), and Klemic et al (1963). They described the transition zone at that locality as consisting of a five to six hundred foot thick section whose exposure was limited to approximately a seventy foot thick conglomerate and sandstone unit. Although the sandstones and conglomerates interfinger and show little lateral continuity, Dyson (1954) noted three general divisions within this unit: 1) a lower dark gray sandstone horizon; 2) a middle dark gray conglomeratic bed; 3) an upper dark gray sandstone layer. He observed pebbles in the conglomerates with diameters of up to two inches. Gault (1957) has recorded a detailed lithologic log of the transition at this locality based on the megascopic description of four cores. He also noted the occurrence of numerous sedimentary structures such as cross-bedding, laminae, graded bedding, scour marks, and evidence of deformed and disrupted bedding.

Investigators have also made some petrographic descriptions of the transition rocks near Jim Thorpe as part of their reports on the uranium occurrences in the area. Montgomery (1954), Klemic (1962), and Klemic et al (1963) have all noted the quartz-rich framework of the sandstones, and Klemic et al (1963) point out the significantly abundant detrital rock fragments. These workers all noted the heavy alteration of the feldspars and biotites and the cementation of the sandstones by calcite and silica.

Pottsville Formation

Lesley (1876) assigned the name Pottsville to the sandstones and conglomerates overlying the red shales of the Mauch Chunk Formation. Later, White (1895) more fully described the lithology of the Pottsville Formation throughout Pennsylvania. The type section at Pottsville, however, was not described until 1900 by White. In 1904, White discussed the history and geometry of Pottsville deposition and concluded that the Pottsville rocks were deposited in a basin formed just west of an associated source developed as a result of a period of continental mountain building. Grabau (1906) attributed a nonmarine environment of deposition with a source consisting of disintegrating crystalline rocks. Grabau believed that the abundance of well-rounded quartz pebbles, presumably due to extensive transportation by rivers and the overlapping nature of the beds away from the source, formed conclusive evidence of fluviatile deposition.

The Pottsville has been recently subdivided into three lithofacies based on mapping and stratigraphic studies by Wood et al (1956): 1) the Tumbling Run member; 2) the Schuylkill member; and 3) the Sharp Mountain member. They also proposed a new type section 150 feet east of White's (1900) section.

Meckel (1967) provides an excellent discussion on the origin of the Pottsville conglomerate based on a thorough sedimentalogical and paleocurrent study in Pennsylvania. His paper includes a lithologic, petrographic, and sediment dispersal pattern description of Pottsville sands. He further elaborated on this information as part of his summary of Paleozoic alluvial deposition in the central Appalachians (1970).

METHODS OF STUDY

Fieldwork

Measured sections of the Mauch Chunk transition zone as well as contiguous portions of the subjacent Mauch Chunk and the superjacent Pottsville Formation were obtained at the four localities previously described. Gross lithology, texture, type of bedding, sedimentary structures, fractures, nature of contacts, and color were recorded for each unit measured. These sections are graphically illustrated in Appendix II.

Specimens for thin sections were taken from the sandstone units by stratified random sampling; however, this approach was modified as additional samples were later needed for more comprehensive studies of several horizons.

Petrographic Examination

Most petrographic data were obtained by standard microscopic examination of 37 thin sections. Qualitative characteristics such as mineralogy, texture, and grain roundness were described first; after this, mineral frequency percentages were estimated by

1000 point counts per slide. In order to cover the entire slide, traverses were made by using a mechanical stage set at 1.0 millimeter (vertical) and 0.5 millimeter (horizontal), following a linear grid system.

The largest diameter of 100 grains on each slide was measured with a scaled reticule to determine average grain size. Median diameters and sorting were calculated from these measurements.

Finally, 100 quartz grains were counted on ten slides to determine the proportion of grains with nonundulatory and undulatory extinction, and the number of crystals per grain.

The composition of pebbles in conglomerate layers was determined by identifying the rock type of 200 pebbles in each of twelve conglomerate samples. Where possible, the pebbles were removed from the sample, crushed and identified; otherwise, they were counted in situ.

Clay Mineral Identification

Samples were analyzed using a Philips powder diffractometer, with $Cu_{K\alpha}$ radiation. Powdered samples on glass slides were run from 2° - 26° 2θ with a scanning speed of 1/2° 2θ per minute and a chart speed of 1/2° 2θ per minute. This resulted in a 1° 2θ per inch printout. To aid in determining the presence of kaolinite or chlorite, one sample was run unglycolated and heat-treated at 450°C. The sample was also run from 24° - 26° 2θ at 1/4° 2θ per minute to resolve the kaolinite-chlorite peak.

Validation Tests

Two statistical methods were employed in order to test the validity of various data. One-way analyses of variance were applied to grain size data between formations and between sections. Population homogeneity of the mineral suite -- calcite, opaques, and plagioclase -- was tested within each formation and between each formation with a chi-square test. These minerals were tested because they displayed the most distinct variation within each section. Individual mineral populations between each formation were also tested by one-way analyses of variance.

LITHOLOGY

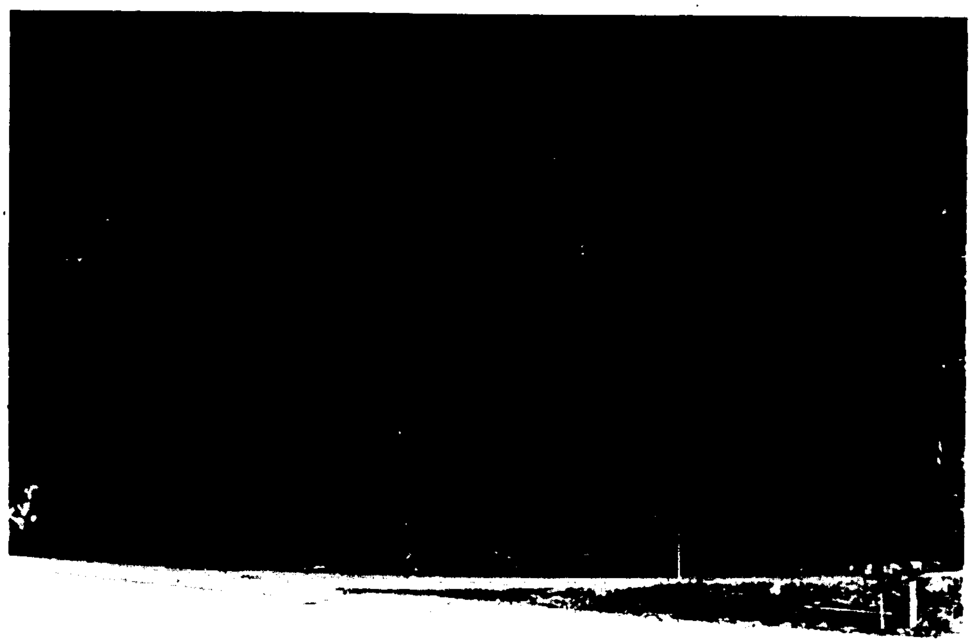
The Mauch Chunk-Pottsville transition is composed of alternating beds of Mauch Chunk type shales and sandstones and Pottsville type sandstones and conglomerates (Figure 2). The Mauch Chunk type rocks in the transition zone are mostly red shales, although, a few beds of red siltstones and very fine-grained sandstones are present. The Pottsville type beds in the transition zone are composed primarily of coarse gray sandstones, conglomeratic sandstones, and conglomerates. In general, there is an upward thinning of the red shales beds and an upward thickening of the gray sandstone and conglomerate beds.

Pottsville Section

The most complete section of the Mauch Chunk-Pottsville transition rocks is exposed 1.6 kilometers south of Pottsville, Pennsylvania along Route 61. The transition zone here is 220.5 meters thick.

The transition red beds are primarily thick, massive, mudstone units containing small lenses and

Figure 2 - Alternating beds of Mauch Chunk type shales (M) and Pottsville type sandstones and conglomerates (P) in the transition zone near Pottsville.

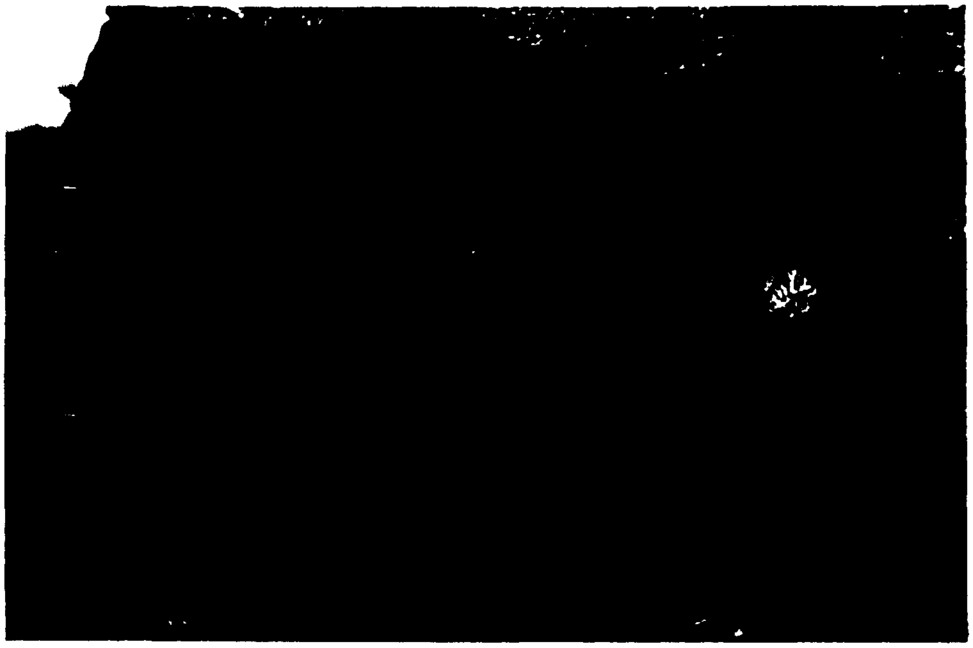


beds of more fissile shale. Color is grayish-red (5R4/2) in the lower and middle parts of the transition, but becomes a paler red (5R5/2) at the upper part of the section. Several horizons (three to five centimeters thick) of calcareous nodules are present in the shale. Mudcracks (Figure 3A), small plant impressions, and scour marks occur on some of the bedding planes.

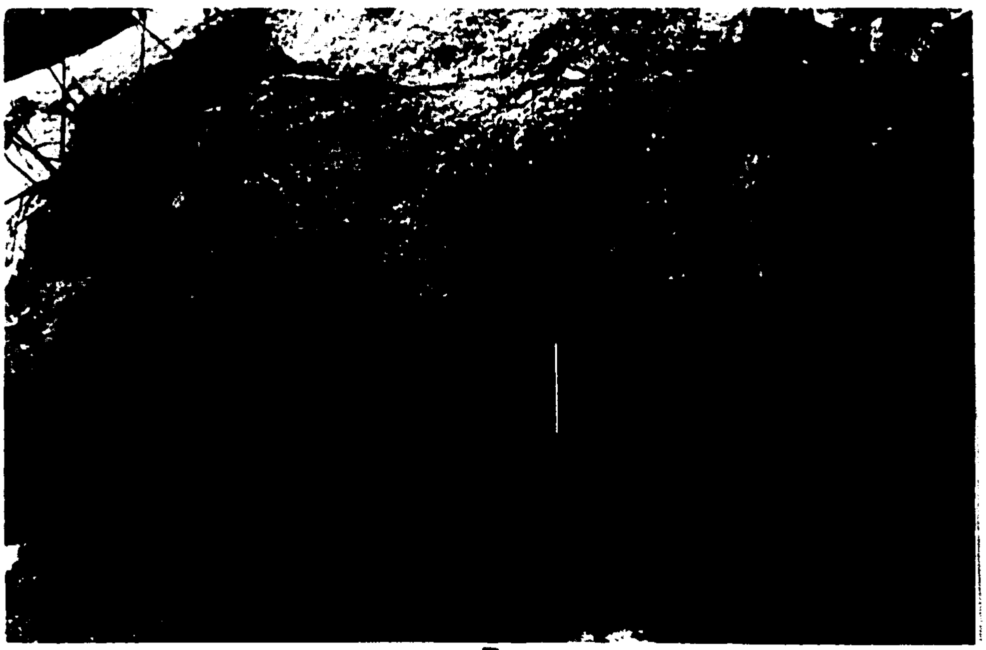
The gray sandstone beds, varying in color from brown grays (5YR5/2) to moderate grays (N5-N3), consist of very thick (five to ten meters, McKee and Weir, 1953) massive sandstones and conglomerates. Internal sedimentary structures are generally absent. Red shale clasts are present in some of the sandstones immediately above the contact with the shale below (Figure 3B). The constituents of the conglomerates generally lack preferred orientation, are poorly sorted, and show a wide range in size of well-rounded pebbles (up to twelve centimeters long). Most of the conglomerates in the section are clast supported and well indurated; however, there are a few relatively poorly consolidated, matrix supported

Figure 3 - A) Mudcracks on bedding plain surface in transition zone shale at Pottsville.

B) Red shale clasts in transition zone sandstone at Pottsville.



A



B

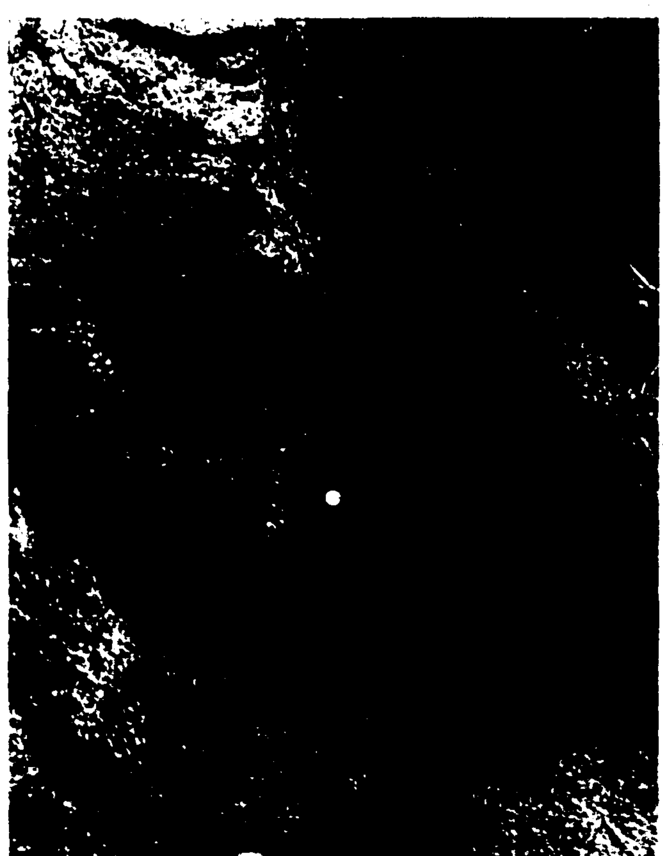
conglomerates in the sequence. Many of the conglomerate beds pinch out or form shallow lenses within the sandstones (Figure 4A), but some form thick uniform beds extending throughout the entire outcrop. Sharp and/or scoured contacts between the sandstones and conglomerate layers and the less resistant red beds are common (Figure 4B). In general, there is an upward thinning of the red shale beds and an upward thickening of the gray sandstone and conglomerate beds.

The Mauch Chunk Formation at this locality generally consists of red (5R4/2) fine-grained sandstones and shales. Planar and herringbone (Reineck and Singh, 1975, page 86) crossbeds (Figure 5A) occur in some of the sandstones. Narrow bands of calcareous nodules are present in several of the shale beds (Figure 5B). In contrast, the overlying Pottsville Formation is dominated by massive conglomerates and coarse-grained sandstones with a few interlayered gray-black fissile shale beds and lenses. Compositional and textural characteristics of the Pottsville rocks are similar to those of the

Figure 4 - A) Lenticular beds of conglomerate in transition zone sandstone at Pottsville.

B) Scoured contact between conglomerate and shale in the transition zone at Pottsville.

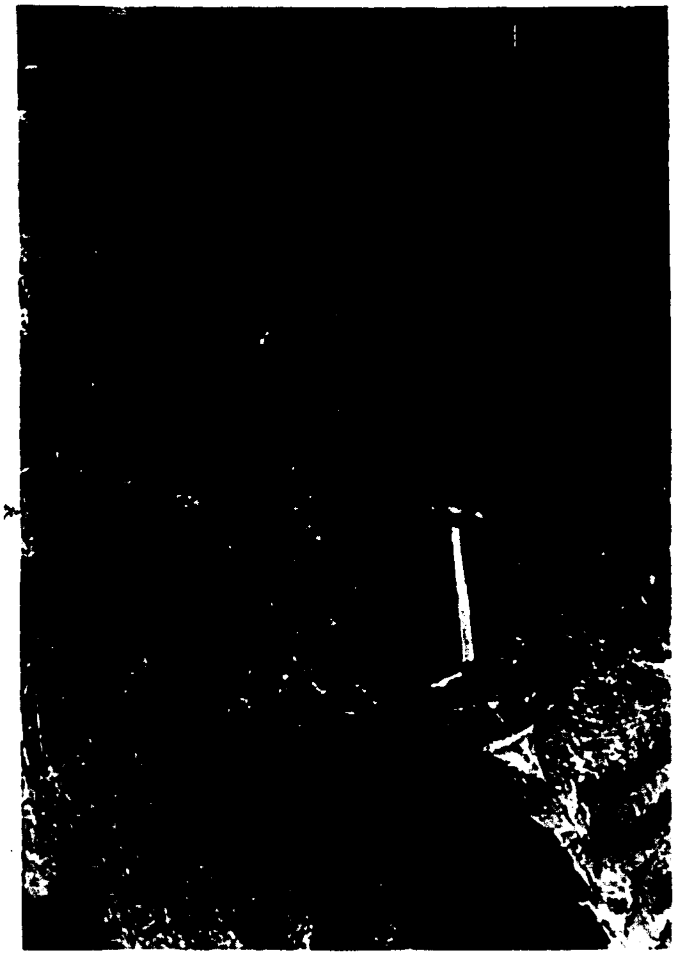
A



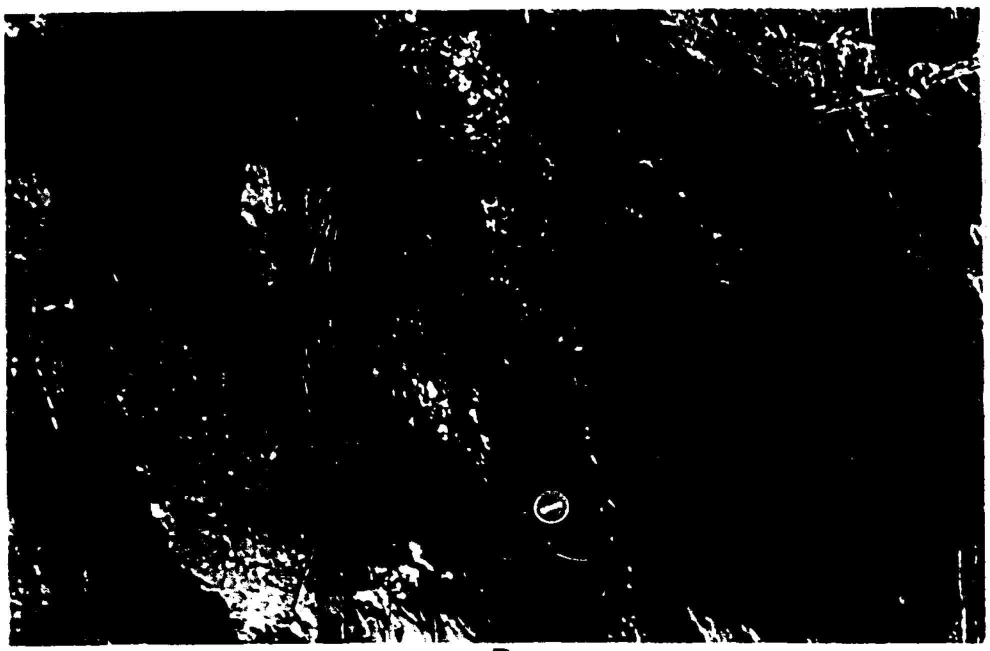
B

Figure 5 - A) Herringbone crossbeds in Mauch Chunk sandstones at Pottsville.

B) Calcareous nodules in transition zone shales at Pottsville.



A



B

sandstones and conglomerates in the transition zone described above. (See Appendix II for measured section).

Jim Thorpe Section

The transition zone at Jim Thorpe on the flank of Mount Pisgah is approximately 163 meters thick, but only the lower 10.5 meters are exposed (Figure 6A). The occurrence of red shale fragments in the soil above the exposure is interpreted to indicate the presence of the transition zone underlying the remainder of Mount Pisgah. This basal unit consists of resistant thickly-bedded coarse dark gray (N4-N3) sandstone grading upward into conglomerates. Sedimentary structures are lacking both in the sandstones and conglomerates; sorting is poor in the conglomerates and most of the pebbles are only moderately to well-rounded. The maximum pebble size observed is four centimeters. Many of the bedding planes display slickensides (Figure 6B) as a result of the intense folding in the area (Klemic et al, 1963).

The Mauch Chunk Formation below the transition

Figure 6 - A) Exposure of the transition zone at Jim Thorpe.

B) Pottsville conglomerates showing slickensided surface (A) on top of Mount Pisgah.

A

B

zone contains thick and some thin (less than 0.25 meters thick, McKee and Weir, 1953) more fissile beds of micaceous red (5R4/2) shale and more resistant beds of fine-grained red sandstone. Fine laminae and planar crossbeds are present in most of the sandstones. Contacts between the sandstone and shale are gradational.

The Pottsville Formation is present on top of Mount Pisgah and is a thick, massive poorly sorted clast supported conglomerate with well-rounded quartz pebbles (Figure 6B). (See Appendix II for measured section).

McAdoo Section

Only 34 meters of the uppermost part of the transition zone are exposed at this locality. Most of the section consists of coarse gray sandstones and quartzose conglomerates; however, two highly fractured, 0.6 meters and 4.6 meters thick respectively, beds of pale red (5R5/2) shale are also present. The conglomerate occurs as massive planar beds or thin lenses within the sandstones. No fabric or sedimentary structures are present and they are generally clast supported. Some of the conglomerates grade into a conglomeratic sandstone. The sandstones are massive without sedimentary structures. The red shale beds are considerably less resistant than the sandstones and conglomerates and weather to small fragments. Gray-green shale and siltstone units are present above and below the highest conglomerate unit within the transition zone. Bedding in this shale unit is less fissile than that in the red beds.

The Pottsville Formation is represented by beds of coarse gray sandstones, conglomerates, and green-gray shales. These rocks are similar to the gray beds in the transition zone described above. (See Appendix II for measured section).

<u>Wyoming-Lackawanna Section</u>

Although there are exposures of both the Pottsville and Mauch Chunk Formations at this locality, only part of the transition zone is uncovered. Most of the exposed section forms a resistant cliff or outcrops in the slope below the cliff. The rocks consist of coarse gray sandstone and red (5R4/2) fissile shale. No conglomerate is present in this section. Most of the sandstone forms massive beds except for a few which contain faint planar crossbeds. The shale occurs as thin (0.6 meters, McKee and Weir, 1953) or thick (0.8 meters, McKee and Weir, 1953) beds and is pronouncedly less resistant than the adjacent sandstones. The shales erode to small fragments. Sharp contacts are characteristic between the red and gray layers.

The upper and lower contacts of the transition zone are covered; however, small outcrops of gray shale representing the Pottsville Formation are present on the ridge above the cliff and the Mauch Chunk is exposed in a riverbed below the section. Here, only fine-grained sandstones of the Mauch Chunk Formation are exposed. Although generally massive, these sands display some faint planar crossbeds. (See Appendix II for measured section).

PETROGRAPHY

Transition Sandstones

Texture

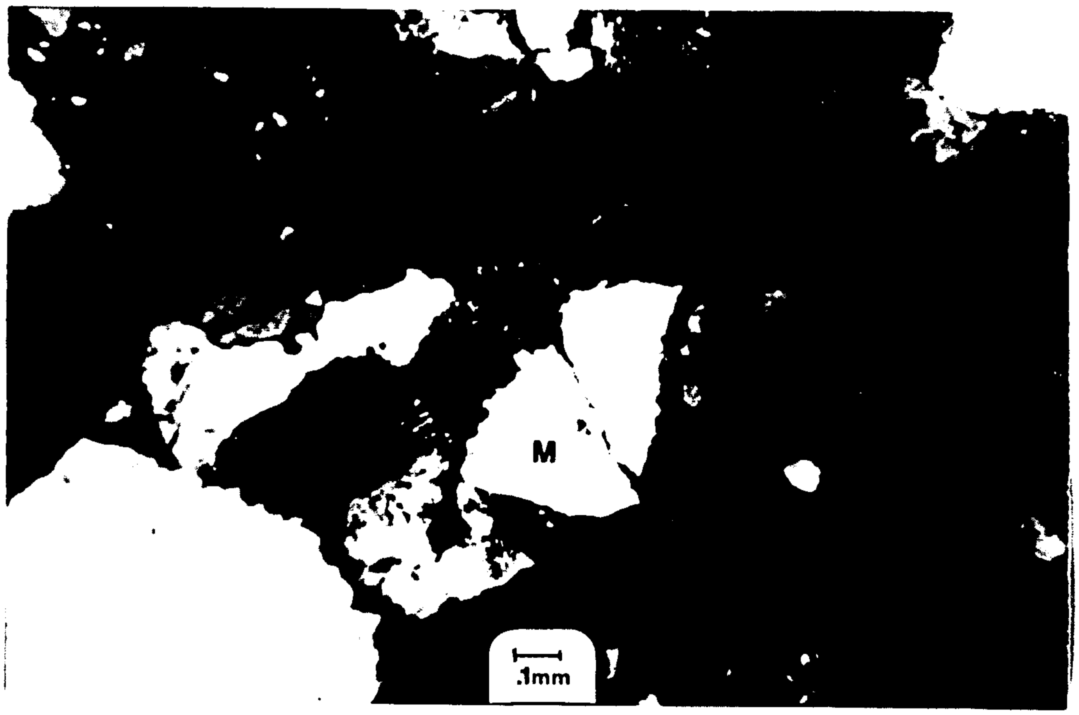
The transition sandstones are moderately sorted (average δ = 0.52), coarse-grained sands with an average grain diameter of 0.56 millimeters.

Most grain-to-grain contacts are point, straight (Pettijohn et al, 1972), and concavo-convex (Pettijohn et al, 1972). The amount of grain contacts has been decreased by the formation of a pseudomatrix (Figure 7) (Dickinson, 1970) which is the intrusion of less competent rock fragments due to compaction into pore spaces adjacent to the framework material.

Most grains are equant; therefore, there is no obvious preferred orientation. However, many of the large elongate mica flakes, unusually elongate quartz grains, and rock fragments lie parallel to bedding.

Cementation of the sandstones is accomplished primarily by precipitated calcite, secondary quartz overgrowths, and a sericite-chlorite matrix (Klemic et al, 1963). Porosity is low to nonexistent due to the cementation and to the filling of pore space by

Figure 7 - Representative photomicrograph of transition zone sandstone under crossed nicols showing monocrystalline quartz (M), vein quartz with semi-composite extinction (V), polycrystalline quartz (Q), and pseudomatrix (P).


M
.1mm

the deformed rock fragments.

The framework grains are angular to well-rounded, most being subangular. Well-rounded grains are restricted primarily to the coarser-sized fraction. These sands can be considered texturally mature.

Framework Mineralogy

The major framework elements include: 1) quartz (monocrystalline quartz and vein quartz); 2) rock fragments comprised of quartzite, metamorphic rock fragments, and lesser amounts of sedimentary rock fragments; 3) feldspars, including both potassium feldspar and plagioclase feldspar, and 4) grains of calcite, chert, mica, and opaques. A few heavy mineral grains are also present in some of the samples.

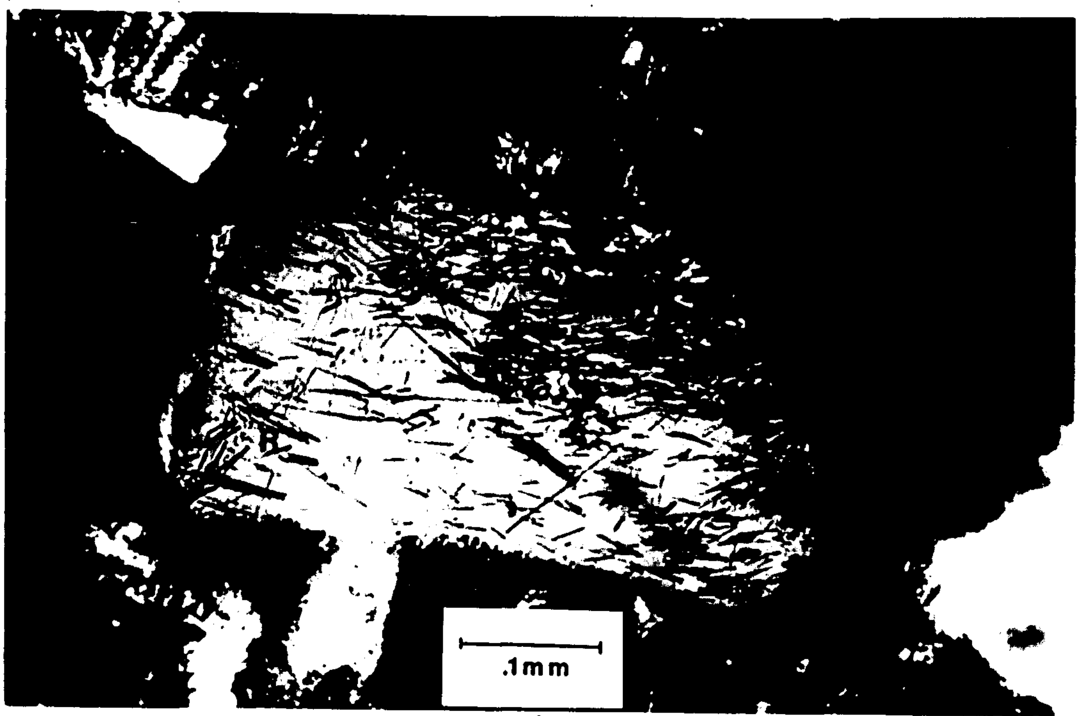
Monocrystalline quartz averages 34 percent by volume and ranges from 10 to 70 percent by volume (Figure 7). Quartz grains of this type are equant to elongate, angular to well-rounded. Most grains are equant and subangular. Most of the larger grains show a higher degree of roundness. Pressure solution, secondary silica overgrowths, and marginal embayments occupied by matrix clays make roundness extimation on some grains difficult. Extinction varies from straight to slightly undulose, (three to five degrees rotation of stage for complete sweep of darkest band across the grain, Hoque, 1968), through strongly undulose (greater than 5° stage rotation for complete sweep of extinction, Hoque, 1968). Most grains are slightly to strongly undulatory. A large number of grains have parallel strain krinkles (Figure 8A). Many of the grains contain numerous vacuoles (Figure 8A) and a lesser amount have inclusions of vermicular chlorite (Figure 8B) or hairlike rutile (Figure 8A).

Vein quartz averages about 7.6 percent by volume (range 1.1 - 46 percent by volume) throughout the entire transition zone. Most vein quartz grains are subangular to well-rounded, although the larger grains generally display a higher degree of roundness. Most grains have semi-composite extinction with a sub-parallel to disordered arrangement of individuals (Figure 7). Abundant vacuoles are present in many of the grains.

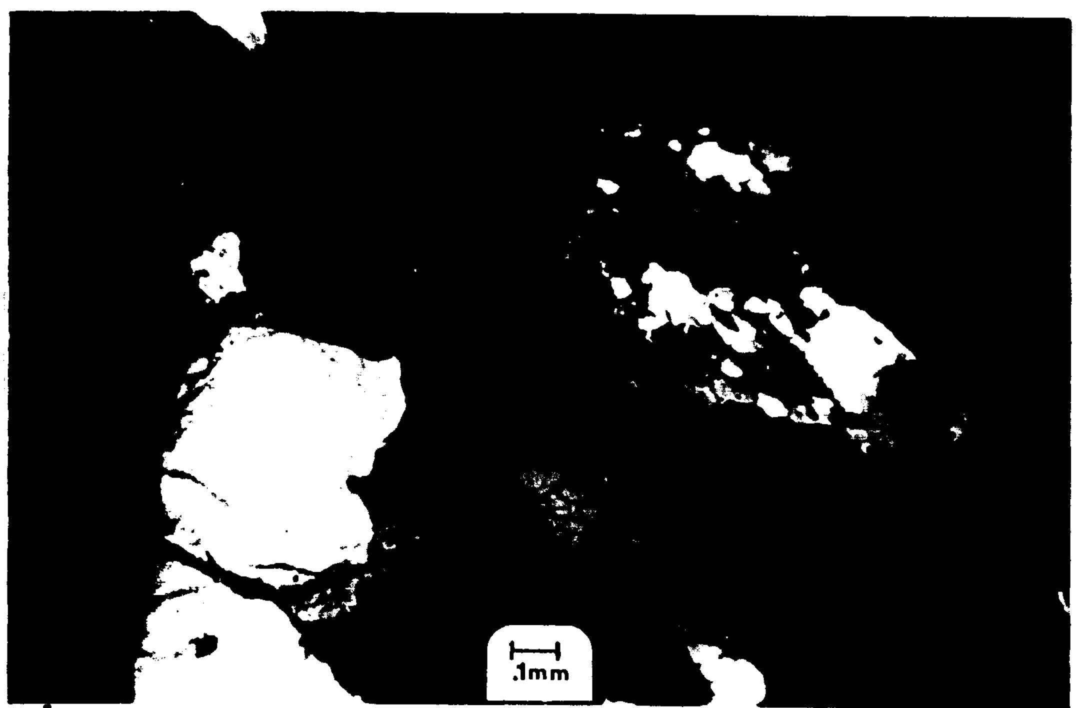
Quartzite, classified as a metamorphic rock

Figure 8 - A) Photomicrograph of transition zone sandstone undercrossed nicols showing rutile needles included in a quartz grain (R), quartz grain with vacuole inclusions (V), and strain krinkles (K0.

B) Photomicrograph of transition sandstone under crossed nicols showing a quartz grain with vermicular chlorite inclusions (V), and quartzite with elongated individuals and composite extinction (Q).



A



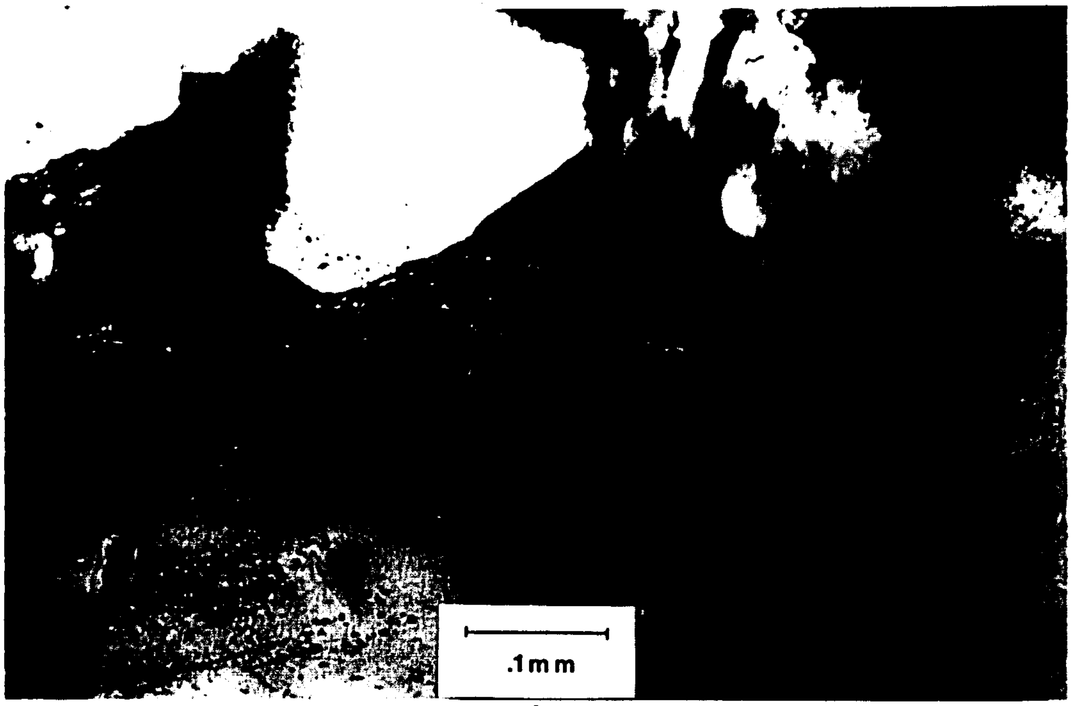
B

fragment in this study, makes up an average of 6.7 percent by volume of the transition sandstones. It ranges from 1.3 percent to 51.3 percent by volume. The quartzite fragments are polycrystalline and have composite extinction due to the highly variable degree of individual crystal orientation (Figure 8B). Most of the quartzite grains are composed of equant individual crystals with little variation in size; however, some grains show a wide range of crystal sizes and/or individuals that are elongated (Figure 8B). Elongation, however, is only slight to moderate. In general, most boundaries between the individual crystals are straight or concavo-convex, although rarely, sutured contacts were observed.

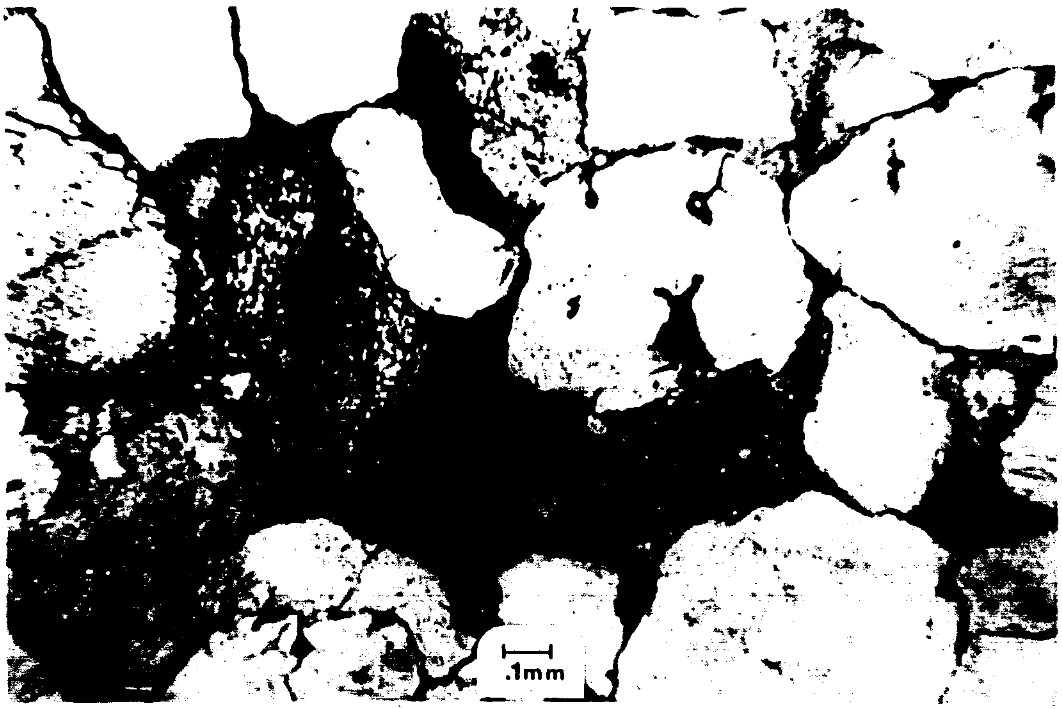
Significantly abundant metamorphic rock fragments are present in all the samples, averaging 14.1 percent by volume and ranging from 3.7 percent to 44.7 percent by volume. Low rank metamorphic rock types, including phyllite and some schist are dominant (Figure 9A and B). The grains are characterized by their micaceous composition and foliation. Most of the metamorphic fragments have been crushed or deformed and squeezed

Figure 9 - A) Photomicrograph showing the early deformation of a phyllite rock fragment (p) (crossed nicols).

B) Photomicrograph of pseudomatrix formed from deformed siltstone rock fragments (S), phyllite rock fragments (P), and a muscovite flake (M) (plane polarized light). Note heterogeneous nature of pseudomatrix.



A



B

into the interstital spaces between the more competent framework grains forming a pseudomatrix. The original elongation is still evident in many of the pseudomatrix grains.

Sedimentary rock fragments, including chert, which is described later, are less abundant than metamorphic types and are comprised of fine-grained sandstone, siltstone, mudstone, and shale fragments (Figure 9A). They make up an average of 1.7 percent by volume of the transition sandstones. Like the metamorphic rock fragments, the sedimentary grains contribute to the formation of the pseudomatrix. Deformation of sand and siltstone rock fragments by elongation is not as prevalent as it is in the metamorphic grains due to their tendency to fragment into their individual components.

Feldspars are common but not abundant (average 7 percent by volume) throughout the section. Potassium feldspar exists as angular to subrounded equant fresh to highly altered grains. They are distinguished from monocrystalline quartz optically by interference figures and by their greater degree of alteration. Numerous grains show edges that have been etched by adjacent matrix material. Vacuole inclusions are abundant in most of the grains.

Plagioclase feldspar is characterized by angular to subangular albite twinned grains (Figure 10) and is restricted to the finer sand fraction. Most plagioclase is fresh, but some grains apparently have been diagenetically replaced by calcite as is evidenced by the large inclusions of calcite in the plagioclase grains (Figure 10). Twinning extinction angles average 12 degrees and the grains yield negative optic signs according to the Michel-Levy method indicating an average composition of $An_{10}Ab_{90}$ (albite-oligoclase).

Calcite is present in the transition zone at only a few specific horizons (Figure 11), especially in the upper part of the section in the Wyoming-Lackawanna Basin, where it reaches a level of nearly 25 percent by volume. In the remainder of the samples that contain calcite, it averages only 4.3 percent by volume. It occurs as a cementing material (Figure 12A) and, to a lesser degree, as

Figure 10 - Photomicrograph of plagioclase feldspar (P) being replaced by calcite (C) (crossed nicols).

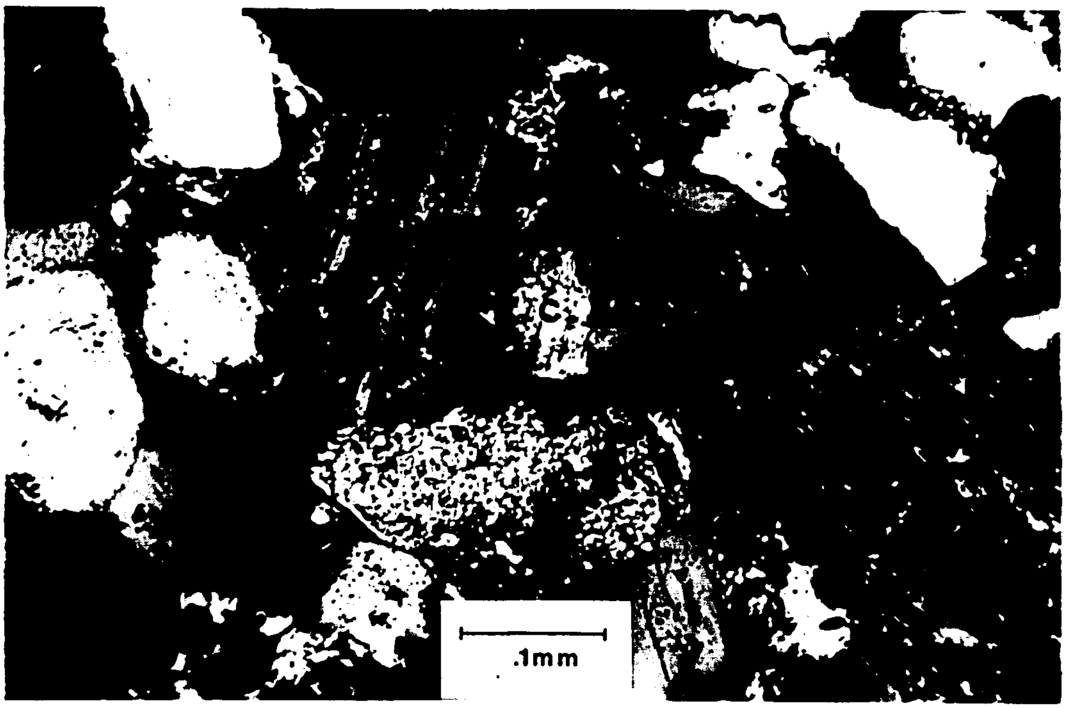
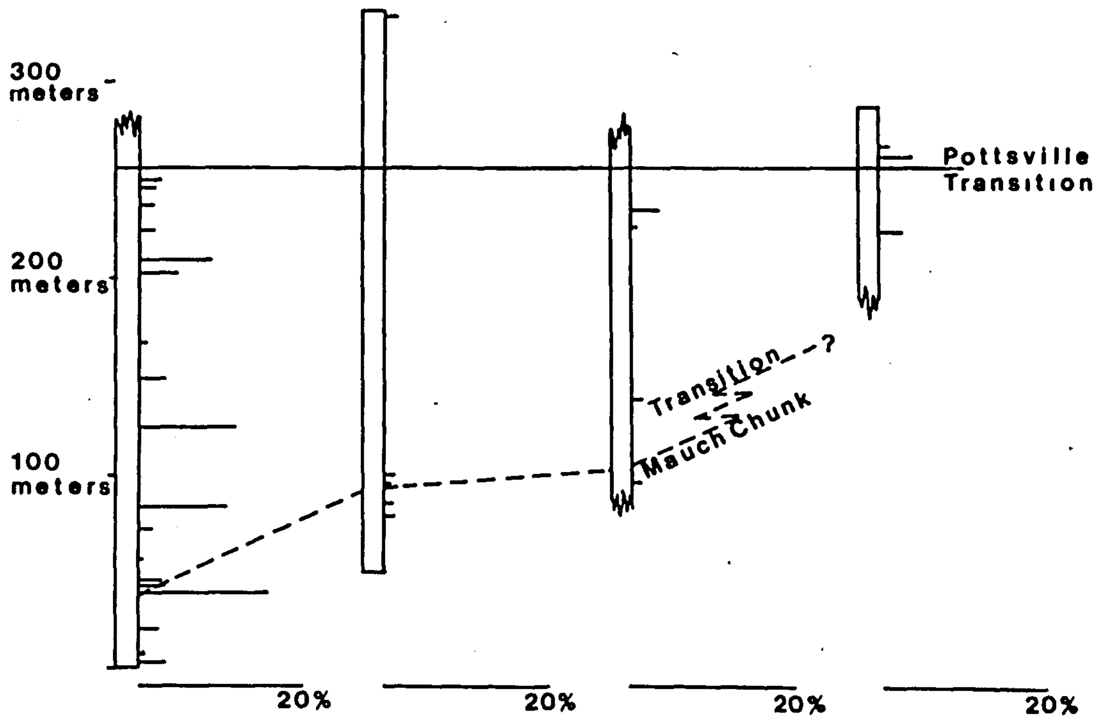

C
.1mm

Figure 11 - Distribution of chert and calcite in the transition zone, in the immediately subjacent Mauch Chunk, and in the superjacent Pottsville Formation.

CHERT



CALCITE

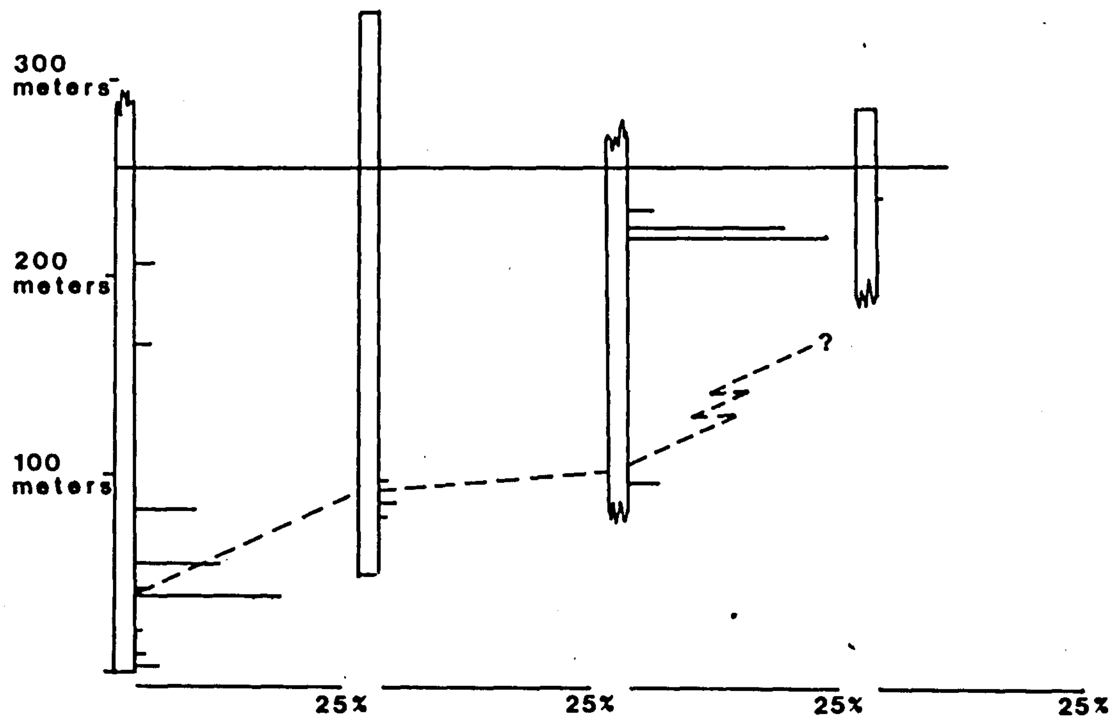
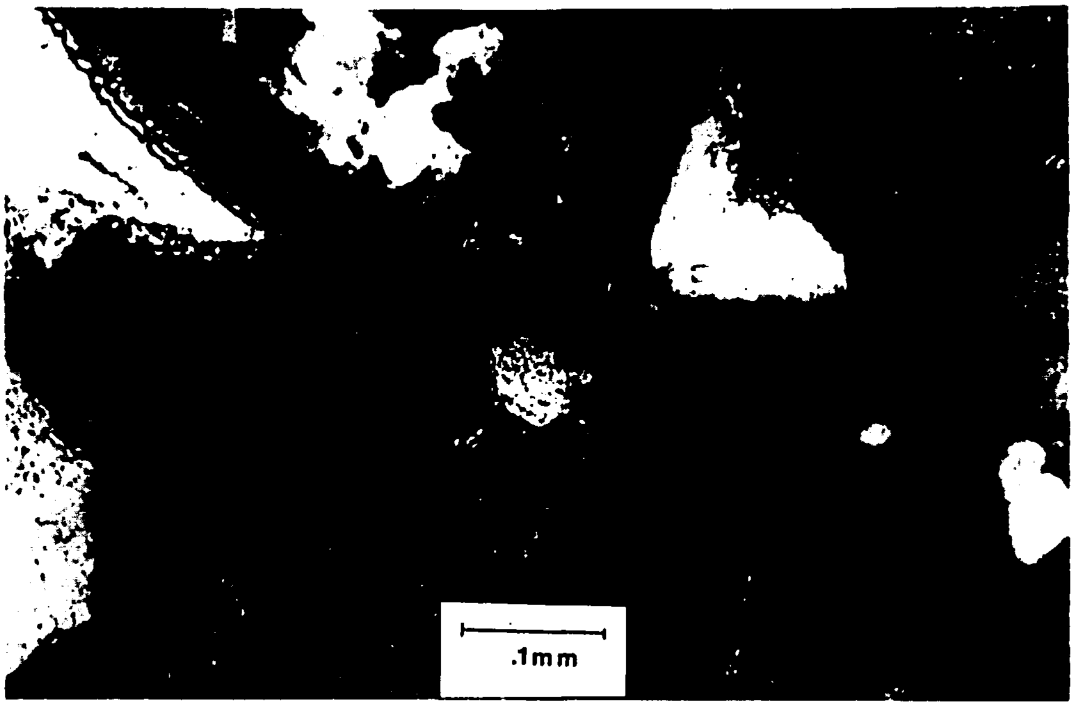
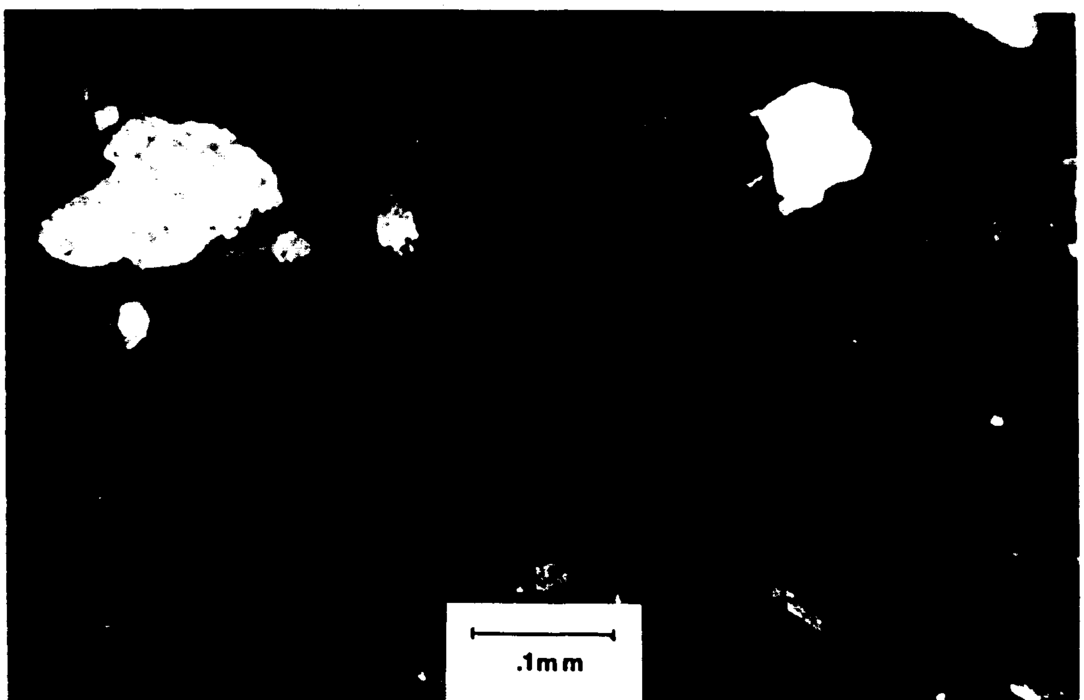


Figure 12 - A) Photomicrograph under crossed nicols of sparry calcite cement (C) causing displacement precipitation and etching of quartz grains (E). Note fragment of quartz in calcite (F).

B) Photomicrograph of a carbonate rock fragment (C) (crossed nicols).



A



B

detrital limestone grains in the framework (Figure 12B). Most of the grains exhibit a high degree of weathering.

Classified as a sedimentary rock fragment, chert is present throughout the transition zone but is not very abundant, averaging only about 2.2 percent by volume of the framework material. It occurs as angular to subrounded, gray to gray-black micro-crystalline and/or relatively coarse microcrystalline grains. Figure 11 shows a positive correlation between the abundance of both chert and calcite, possibly reflecting the common association of chert nodules in limestone.

Large flakes of muscovite (Figure 9B), rarely exceeding 1 percent, are present in most samples and in a few samples, biotite was observed in trace amounts. Dickinson (1970) questions whether mica flakes should be included in the framework material due to their unusual hydrodynamic characteristics relative to the more equant shaped and denser quartz, feldspar, and rock fragment grains. Most of the mica has been deformed and conforms to framework grain boundaries.

Chlorite occurs as vermicular inclusions in numerous quartz grains and in some samples, chlorite flakes occur in the matrix.

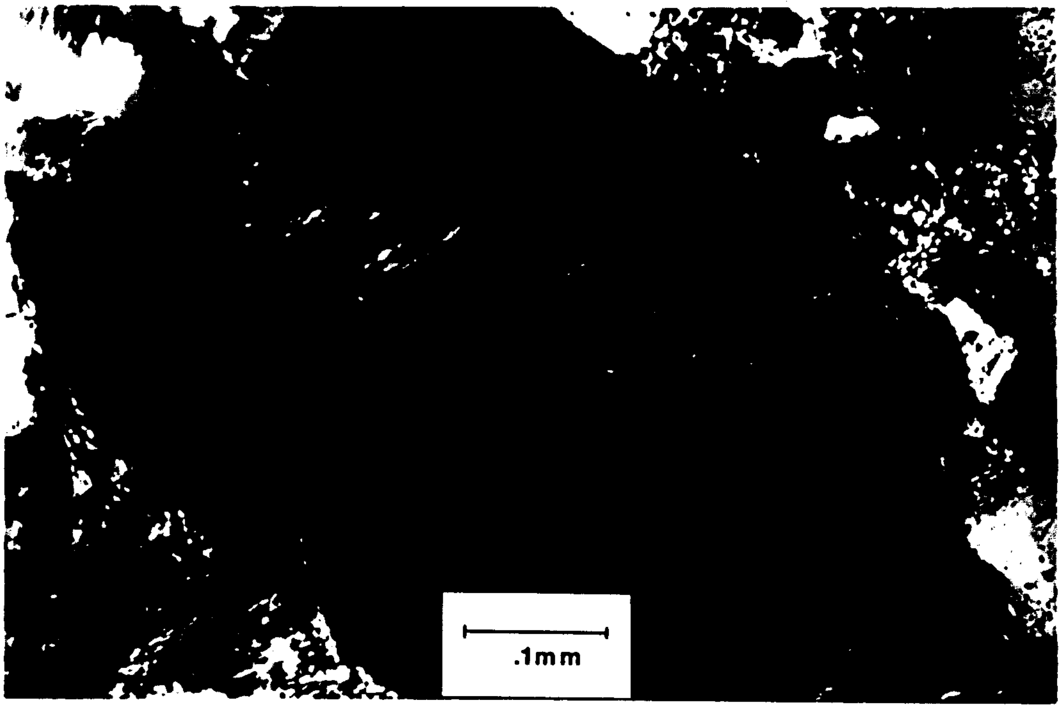
The minor minerals, including the opaques, and nonopaque-nonmicaceous varieties, are present in only trace amounts, although in three samples, opaques constituted about 2 percent of the framework. The only opaque mineral present was hematite identified by its characteristic red color. Klemic et al (1963) reports the occurrence of magnetite as well.

The heavy mineral suite includes: tourmaline, diopside, zircon, hornblende, pyroxene, and garnet. Tourmaline and diopside are the most common species present. Although not observed in this study, uraniferous minerals occur in the basal conglomeratic unit at Jim Thorpe (Klemic et al, 1963).

Matrix

Detrital matrix material, (individual grains less than 0.03 millimeters in diameter, Hoque, 1968), occurs rarely in the transition rocks. Numerous occurrences of small interstital fragments are present, but these are presumably fragments of crushed framework grains. Most interstices are filled with incompetent argillite, siltstone, phyllite, and schist rock fragments that have been squeezed and deformed by more competent framework material (Figure 9B). The result is the formation of a matrix-like mask that has been given the term "pseudomatrix" by Dickinson (1970). He gives several criteria for distinguishing pseudomatrix from true matrix. Those that apply to this study are: 1) "wisps" of crushed lithic material extending into narrow orifices between framework grains (Figure 13), 2) a lack of lithologic homogeneity throughout the matrix material compared to the consistent composition of a true detrital matrix (Figure 9B), 3) the identification of relic lithic fragment textures. It is important that the distinction between pseudomatrix and other matrices is accurate; otherwise, an overestimation of detrital matrix material will be made.

Figure 13 - Photomicrograph showing an extremely crushed rock fragment forming "wisps" of pseudomatrix (W) and a microstylolite (M) (crossed nicols).


.1mm

Cement

There are two primary forms of cementation in the transition rocks. These are: 1) cementation by calcite, and 2) cementation due to quartz overgrowths. To a lesser degree, matrix material also has contributed to cementation (Klemic et al, 1963).

Calcite cement occurs mostly as large single crystals of optically continuous precipitates with numerous twinned laminae that surround a consequently "floating" framework, which Scholle (1979) refers to as a poikilotopic texture (Figure 12A). Some of the carbonate cement also exhibits a micritic texture individually filling interstices. There is a direct correlation between the abundance of detrital carbonate and the amount of calcite cement, suggesting that the detrital calcite is the source for the cement.

Although difficult to observe in the thin sections in this study, cementation by quartz overgrowths is evidenced by the abundant concavo-convex and sutured grain contacts in some samples. A few overgrowths are revealed by the presence of remnant rims outlining the original grains (Figure 14).

Conglomerates

Conglomerates are present in all of the measured sections except in the Wyoming-Lackawanna Basin. They vary from very poorly sorted, disrupted matrix supported to highly consolidated clast supported rocks, the latter with a higher degree of sorting. Most conglomerate beds display a channelized morphology characterized by shallow lenticular and wedge-shaped beds and crosscutting of the subjacent sands and shales (Figure 4A). Tabular beds are also common in many of the conglomerate units. The conglomerates are essentially massive with no internal structures.

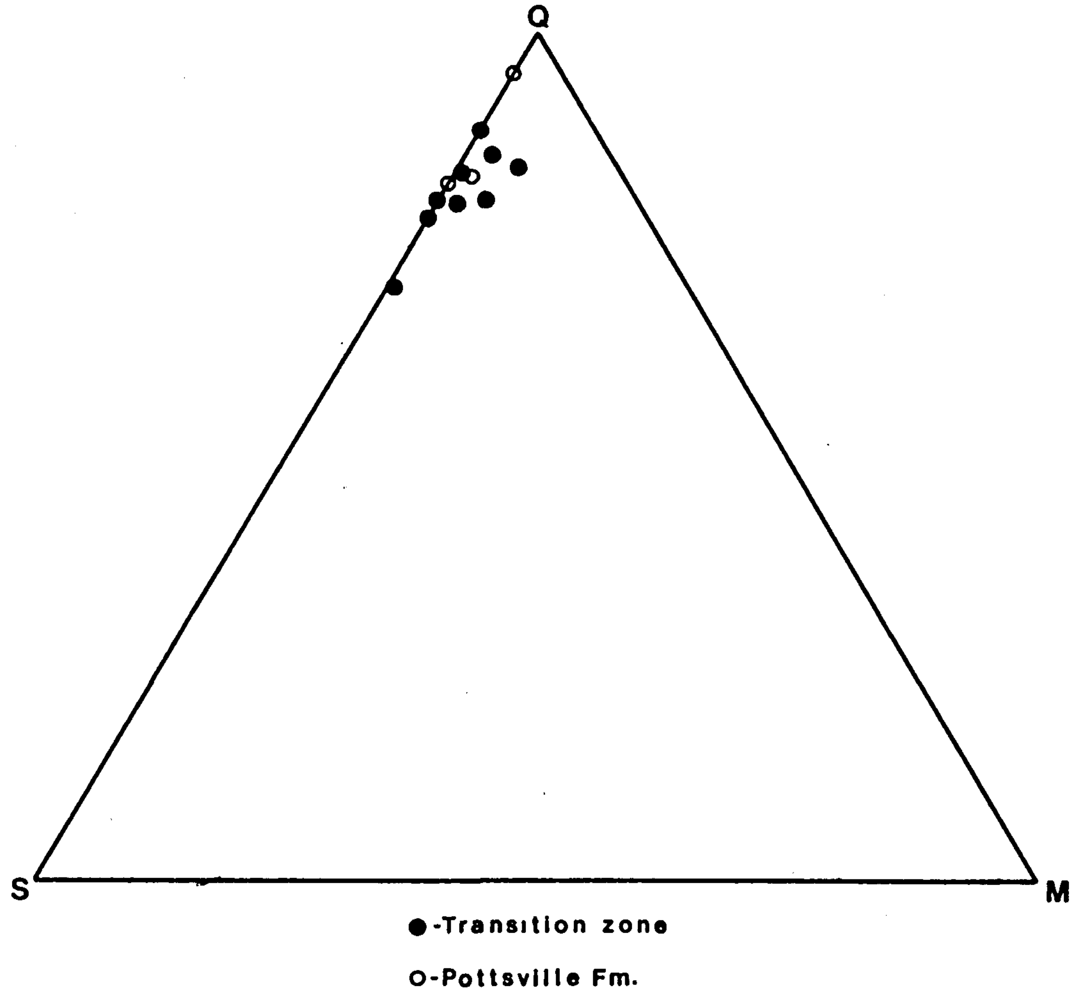
The main elements of the conglomerates are the sand, matrix, pebbles, and cobbles. Red shale clasts are present just above some of the basal conglomerate contacts, presumably rip-up fragments from the subjacent material. Pebbles and cobbles encompass a wide size range with diameters of over 12 centimeters observed. Most of the pebbles display a high degree

Figure 14 - Photomicrograph of quartz overgrowths (O), and remnant outlines of host grains (R). Note calcite cement replacing quartz overgrowth (C) indicating that silica precipitation occurred prior to calcite cementation. (crossed nicols)


O
R
R
O
.1mm

of sphericity (.75) and roundness (.7). The most common pebble type is vein quartz, which is present in amounts greater than 75 percent in all but one of the samples (Figure 15). Lesser amounts of quartzite, graywacke, phyllite, chert, and argillaceous material comprise the remainder of the pebble population. Pettijohn (1957) classifies these types of rocks as oligomictic conglomerates, since their pebble populations are comprised mostly of stable vein quartz pebbles. Less mature polymictic conglomerates contain significant amounts of unstable pebble types, such as graywackes and metamorphic rock fragments. According to Pettijohn (1957) and Meckel (1967), vein quartz pebbles represent a mature and stable lithologic suite relative to weathering. Vein quartz pebbles exhibit the highest degree of roundness (.75 - .8) and sphericity (.75 - .8) due to their relatively higher resistance to weathering. Pebble fabric is random and lacks any visible preferred orientation.

Figure 15 - Composition of pebbles in transition zone and Pottsville conglomerates Q-Qtz (including vein quartz and quartzite) pebbles, S-sedimentary rocks, M-metamorphic rocks.


Q
S
M
●-Transition zone
o-Pottsville Fm.

Mauch Chunk Sandstones Below the Transition Zone

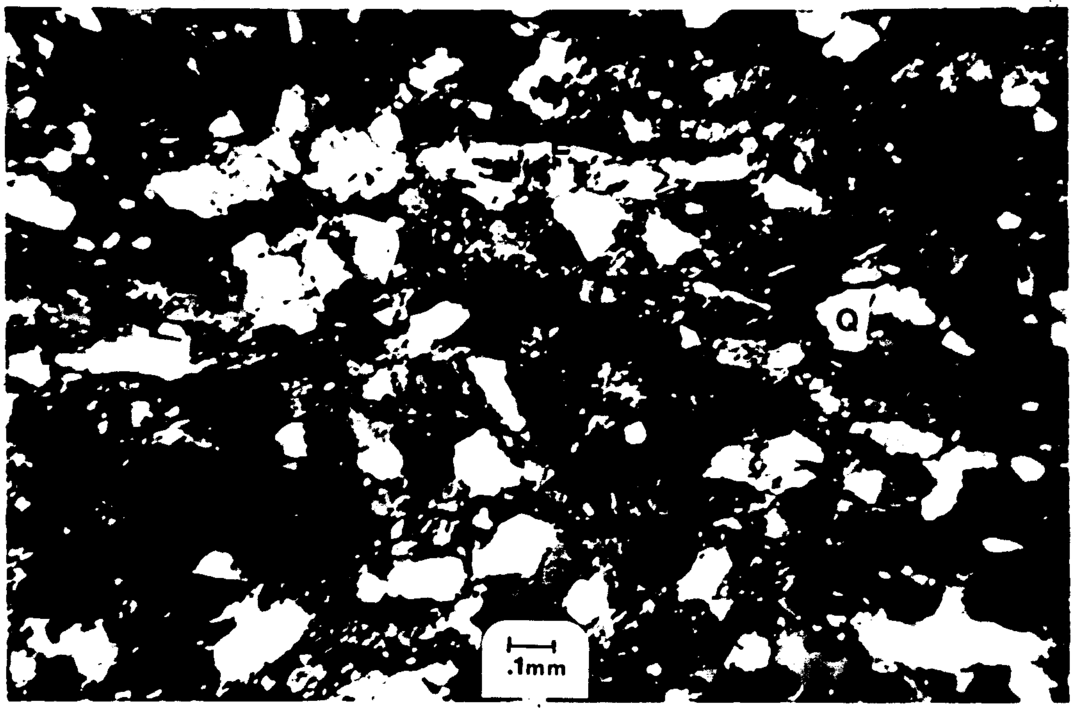
The Mauch Chunk sandstones are primarily fine-grained (average 0.19 millimeter) and moderately very well sorted (average δ= 0.31).

The framework of subtransition zone Mauch Chunk sandstones consists primarily of monocrystalline quartz, vein quartz, quartzite, chert, potassium and plagioclase feldspar, and a few opaques (Figure 16A). Framework grains of these types generally are surrounded by a pseudomatrix formed from crushed and squeezed less competent rock fragment grains. Phyllites (most abundant), argillaceous material, and schists dominate the rock fragment population, which averages about 20 percent by volume. The framework grains are generally equant and angular to subangular, although, as in the transition zone, larger grains exhibit a higher degree of roundness. The fabrics of Mauch Chunk sandstones are likely to be laminated due to the presence of elongated framework grains and rock fragments (Figure 16A). Grain-to-grain relations vary greatly, ranging from sutured contacts (rare) to point-to-point contacts. Few grains are "floating" in

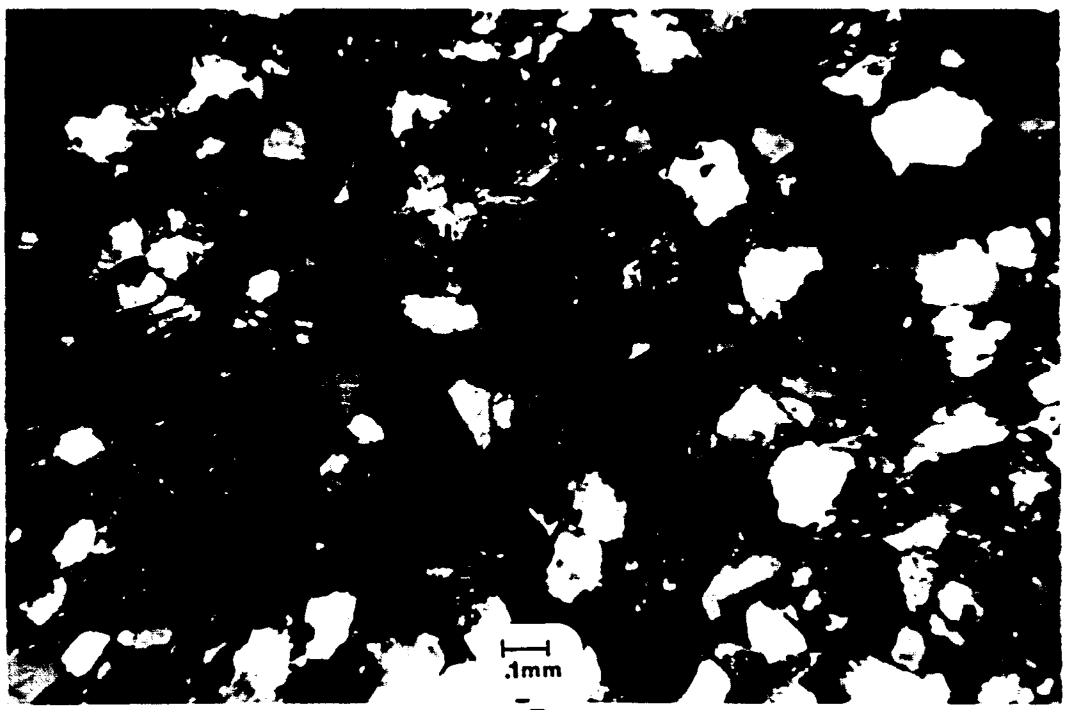
Figure 16 - Representative photomicrographs of Mauch Chunk sandstones

A) elongate grains (E), opaques (O), muscovite flake (M), monocrystalline quartz (Q)

B) plagioclase feldspar with albite and carlsbad twinning (P), and severely undulatory quartz (U) (crossed nicols)



A



B

an abundance of pseudomatrix. Most contacts are irregular-straight or concavo-convex. These sandstones are mature.

Quartz content, (including monocrystalline quartz and vein quartz), in the Mauch Chunk sandstones is high, averaging about 40 percent by volume. Most quartz grains are monocrystalline and show a moderate to high degree of undulatory extinction. Numerous grains contain vermicular chlorite inclusions. Unlike the transition zone, no grains were observed with inclusions of rutile. Strain krinkles are present on some grains, but their abundance is not as great as that in the transition rocks.

Quartzite grains contain randomly oriented, equant to elongate individuals with straight to sutured boundaries. In most grains, the size of the individuals is uniform, but in some, there is more of a bimodal size distribution.

Vein quartz averages 5.0 percent in the Mauch Chunk sandstones. It occurs as subangular to rounded grains with semicomposite extinctions. Most of the individuals are randomly oriented or, in a few cases, subparallel.

Chert is present as gray to gray-black microcrystalline, subangular to subrounded grains. Some grains show a micro- and/or coarse microcrystalline texture. Showing no statistical difference in abundance from the transition zone, chert in the Mauch Chunk Formation averages about 1.8 percent by volume.

Potassium feldspar averages approximately 13 percent by volume, much of which is altered to sericite and calcite (Hoque, 1968).

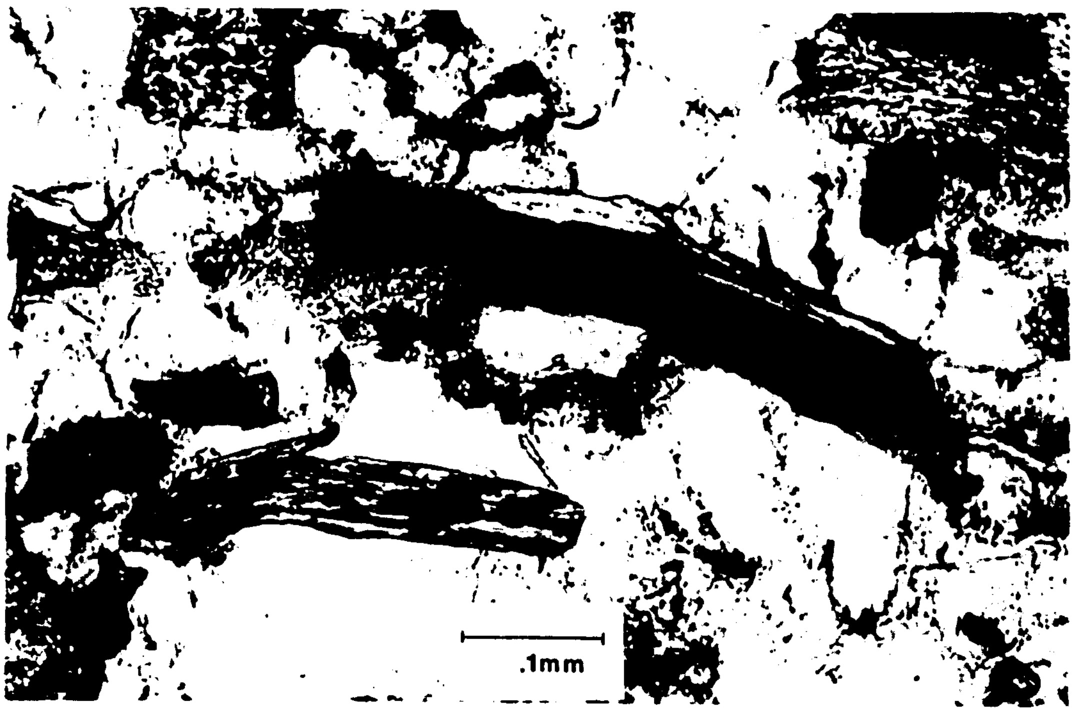
The components that show the most significant quantitative difference between the transition and Mauch Chunk Formations are plagioclase feldspar, calcite, and opaque materials. Sodium-rich plagioclase feldspar, although not abundant (0.6 percent by volume), is present in all of the Mauch Chunk samples. It occurs as fresh, angular to subangular grains displaying albite twinning or both albite and carlsbad twinning (Figure 16B). Plagioclase composition, determined with the Michel-Levy method, averages about $An_{29}Ab_{71}$ (oligoclase).

Unlike its sporadic occurrence in the transition zone, calcite occurs throughout the entire Mauch Chunk Formation examined in this study, as detrital material and most commonly as cement. Calcite averages 2 percent by volume and usually occurs as isolated micritic interstitial patches. Minor amounts of optically continuous sparry calcite cement are also present.

Both muscovite and biotite are present in all samples studied, and together average 1.5 percent by volume. Mica occurs as flakes that are deformed by, and conformed to, framework grain boundaries or are concentrated on bedding plane surfaces. Most flakes lie with their long axes parallel to bedding. Most of the muscovite is fresh material and some of the less abundant biotite is altering to chlorite or hematite (Figure 17) (Hoque, 1968).

Opaques average about 1.4 percent by volume in the Mauch Chunk sandstones and occur mostly as matrix or as coatings on detritus, which give the rocks their characteristic red color. According to Hoque (1968) and Epstein et al (1974), they are iron oxides

Figure 17 - Photomicrograph of biotite flake altering to an opaque mineral (B), presumably hematite in the Mauch Chunk Formation. Note deformity of muscovite flake (M). (crossed nicols)


.1mm

occurring as hematite or limonite.

Non-framework material includes a matrix composed of previously mentioned iron oxides, broken rock fragments, muscovite, biotite, and chlorite. In general, matrix material is more abundant in the Mauch Chunk; however, it does not exceed 5 percent by volume. The term matrix here refers to non-pseudomatrix material containing grains which are less than 0.03 millimeters in diameter (Hoque, 1968).

Cementation consists of calcite and, to a lesser degree, quartz overgrowths and matrix. Calcite cement is distributed in discontinuous patches surrounding framework grains. Secondary quartz is difficult to identify because of its optical continuity with the unoutlined host grains. Although no instances were observed by this writer, Klemic et al (1963) and Hoque (1968) both cite the presence of quartz overgrowths in the Mauch Chunk Formation.

The heavy mineral suite, as observed in thin section, includes mostly tourmaline and zircon with minor amounts of diopside, hornblende and a trace of garnet. Montgomery (1954) reports the presence of olivine; however, this mineral was not observed in this study. A few isolated opaque grains, probably magnetite or ilmenite, were noted. These phases were also reported present by Klemic et al (1963).

This suite differs little from that found in the transition zone.

Pottsville Sandstones

The Pottsville includes texturally mature, medium- to coarse-grained sandstones and quartzose conglomerates. The average grain size of the sandstones is 0.9 millimeters with some grains ranging into pebble size (greater than 4 millimeters in diameter). The sandstones are supported by framework grains consisting primarily of monocrystalline and vein quartz, quartzite, chert, and lesser amounts of potassium feldspar (Figure 18). Roundness of framework grains ranges from angular to well-rounded, but most grains are subangular to subrounded. Most of the larger sand grains and pebbles are characteristically rounded to well-rounded. The degree of

Figure 18 - Representative photomicrograph of Pottsville sandstone showing monocrystalline quartz (M), vein quartz with subparallel individuals (V), quartzite (Q), and pseudomatrix (P) (crossed nicols).


M
.1mm

roundness appears to be somewhat higher in the Pottsville than in the transition zone. Most grain contacts in Pottsville sandstones are point-to-point, straight, or concavo-convex. As in the transition rocks, a pseudomatrix made up of crushed and deformed, low- to medium-grade metamorphic, argillaceous and sedimentary rock fragments is present in the interstices.

Monocrystalline quartz is the chief framework constituent averaging 30 percent by volume and ranging from 10.5 to 50 percent by volume. Similar to the transition zone quartz, most of the quartz in the Pottsville occurs with a slightly undulose extinction and numerous vacuole inclusions. Some grains exhibit strain krinkles and/or inclusions of rutile or vermicular chlorite.

Vein quartz makes up about 13 percent by volume of the material. It generally exhibits a semi-composite extinction with equant to elongated sub-parallel individuals.

Potassium feldspar is petrographically similar to that found in the transition zone, and is characterized by angular to subangular grains, most of which are, as reported by Klemic et al (1963), partially altered to sericite. No plagioclase was observed in the Pottsville samples studied. Petrographically, the Pottsville and transition cherts are identical and no calcite is present in the Pottsville rocks examined.

A detrital matrix consisting mostly of sericite (Klemic et al, 1963) and broken rock fragments, and secondary quartz provide most of the cement. Quartz overgrowths are difficult to distinguish; however at least a few are present.

The Pottsville conglomerates resemble those occurring in the transition zone, and are characterized by very poorly sorted matrix and clast supported material. The pebbles, averaging 3 to 4 centimeters in diameter, are almost all well-rounded (0.7), and are comprised mostly of vein quartz and lesser quantities of chert, sandstone, phyllites, and argillaceous material (Figure 15). Red shale clasts are absent. The matrix material is a coarse sand similar to that described above.

The conglomerates are massive, showing no visible sedimentary structures or preferred orientation of pebbles. Beds generally are wedge-shaped or lenticular, but some beds tabular in outcrop are also present. The lenticular beds may represent shallow channel fill, from 1 to 3 meters thick, cut into massive sandstones. At both the Pottsville and McAdoo sections, some of the sandstones grade into conglomeratic sandstones.

Shales

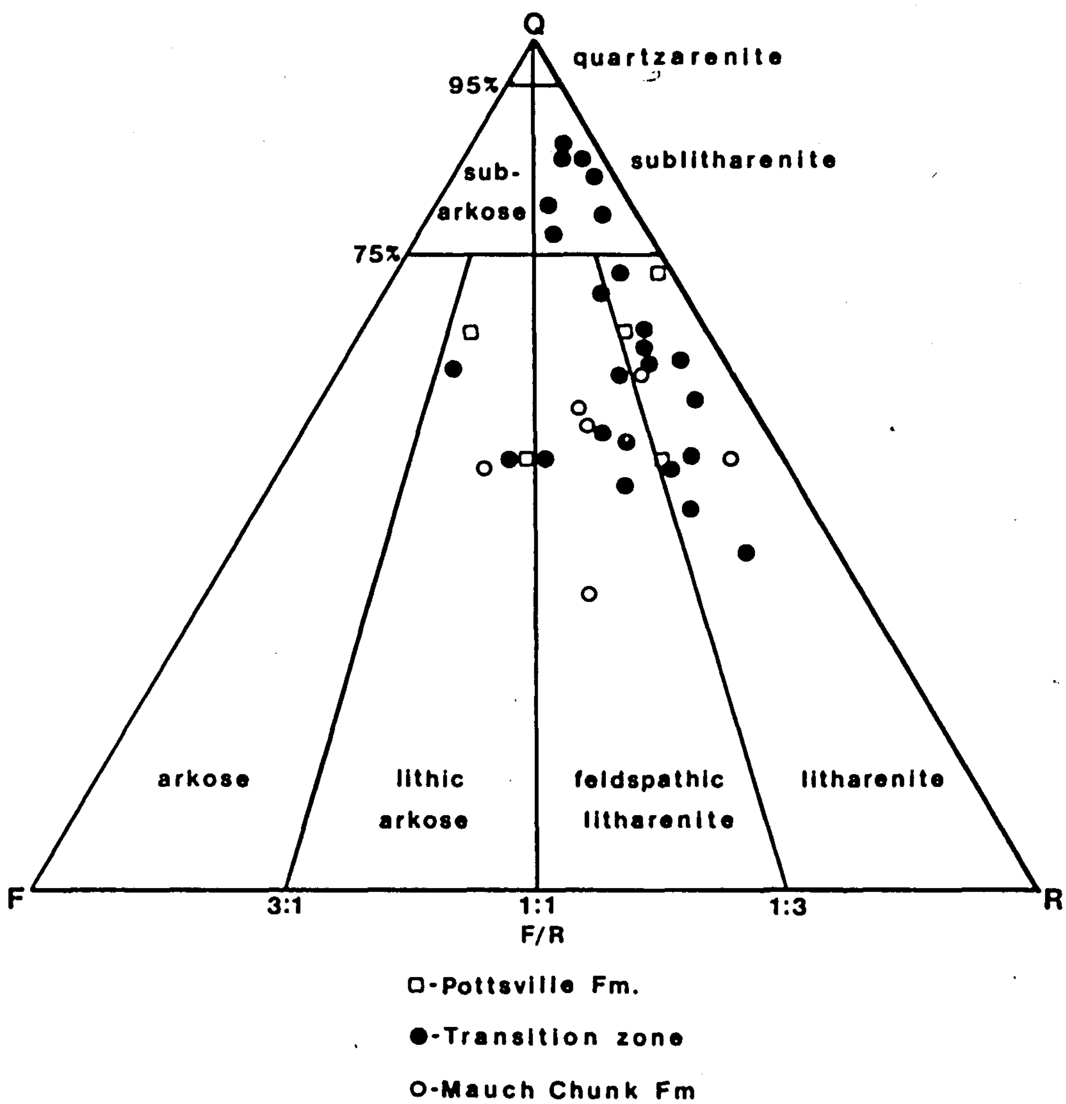
Qualitative X-ray analysis of the shales in the transition zone and those immediately superjacent in the Pottsville Formation and immediately subjacent in the Mauch Chunk Formation show that they are comprised mostly of illite, chlorite, muscovite, and quartz. Illite is the dominant clay mineral and chlorite decreases up-section until it disappears in the Pottsville shales. The reason for the change in chlorite content is uncertain.

Classification

All of the transition, Mauch Chunk, and

Pottsville rocks have frameworks that contain mostly quartz and rock fragments; therefore, according to Folk's (1974) classification scheme for arenites, they are all classified as litharenites or lithic arkoses (Figure 19). They can be further divided into subclasses depending on the relative amounts of quartz and feldspar in the rock (Fold, 1974, page 129). Forty-two percent of the samples contain minor (average about 10 percent) amounts of feldspar and are classified as litharenites. Twenty-five percent have a 1:1 - 1:3 percent ratio of feldspar to rock fragments and are grouped as feldspathic litharenites. Fourteen percent of the samples show slightly greater proportions of feldspar than rock fragments and are considered lithicarkoses. The remaining 19 percent are characterized by a greater than 75 percent by volume quartz framework and are classified as sublitharenites. The rocks can be more specifically named according to the dominant rock fragment or, if arkosic, feldspar type. Most of the samples are classified as phyllarenites, feldspathic phyllarenites, or subphyllarenites

Figure 19 - Composition and classification of arenites in the Mauch Chunk (including those in the transition zone) and Pottsville Formations in the area of study. Rock type names shown are those of Folk (1974). Q-mono- and polycrystalline and veinquartz, R-lithie fragments, including chert, F-feldspars.


Q
quartzarenite
95%
sub-
arkose
sublitharenite
75%
arkose
lithic
arkose
feldspathic
litharenite
litharenite
F
3:1
1:1
F/R
1:3
R
□-Pottsville Fm.
●-Transition zone
○-Mauch Chunk Fm

because of the abundance of metamorphic rock fragments. The specific name for each sample can be found in Appendix I.

DISCUSSION

Comparison Between the Transition, Mauch Chunk, and Pottsville Sandstones

The transition zone sandstones and conglomerates are petrographically similar to the Pottsville sandstones studied and significantly different from the Mauch Chunk sandstones studied. In contrast, the shale layers in the transition zone are mineralogically similar to the shales of the Mauch Chunk and are unlike the shales observed in the Pottsville.

The transition sandstones and conglomerates and the Pottsville sandstones and conglomerates are generally gray, or olive-gray in contrast to the sands of the Mauch Chunk Formation below the transition zone. Similarly, the red color of the transition and Mauch Chunk shales distinguishes them from the gray shales of the Pottsville Formation. The Pottsville and gray transition rocks are mostly medium- to coarse-grained sands with interbedded conglomerates showing little preferred orientation of framework grains or sedimentary structures. This differs from the characteristically finer-grained

Mauch Chunk sandstones that are cross-bedded or, in places, laminated. The characteristic lenticular, wedge-shaped, or channel fill sandstones of the Mauch Chunk transition are not present in the underlying more homogeneous Mauch Chunk sands.

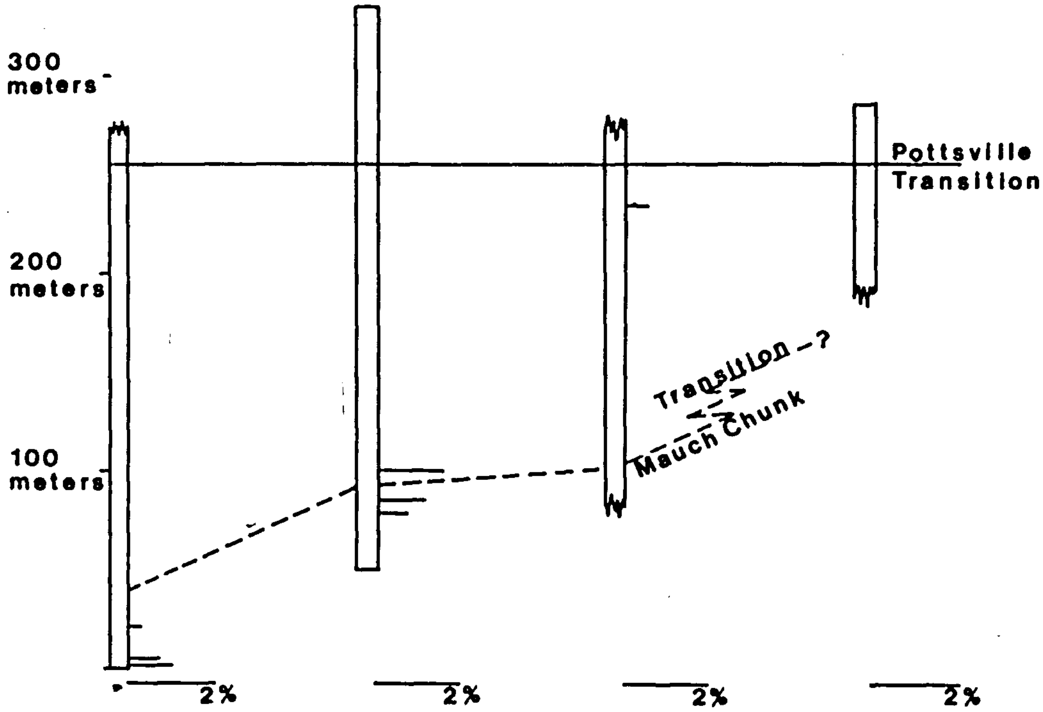
One-way analysis of variance shows that at the 90 percent confidence level, the average grain size of sandstones in the transition zone is statistically equivalent to sandstones of the Pottsville ($F= 2.70$, df treatment= 1, df error= 29, critical $F= 2.89$), but the transition sandstones are statistically coarser than the rocks in the Mauch Chunk Formation $F= 4.16$, df treatment= 1, df error= 30, critical $F= 2.88$). The Mauch Chunk sands are significantly better sorted than the sandstones in the transition. The lack of any preferred orientation of grains in the transition and Pottsville sandstones contrasts with the occurrence of numerous elongate grains with their long axes aligned parallel to bedding in the Mauch Chunk below the transition.

Although the ubiquity of quartz and rock fragments precludes their use as diagnostic comparative evidence and a chi-square test shows that, statistically, the transition sandstones and conglomerates are mineralogically homogeneous, distribution trends of the sparsely occurring calcite, plagioclase, and opaque minerals have enabled this writer to make a comparison between the transition zone, the underlying Mauch Chunk, and the superjacent Pottsville rocks.

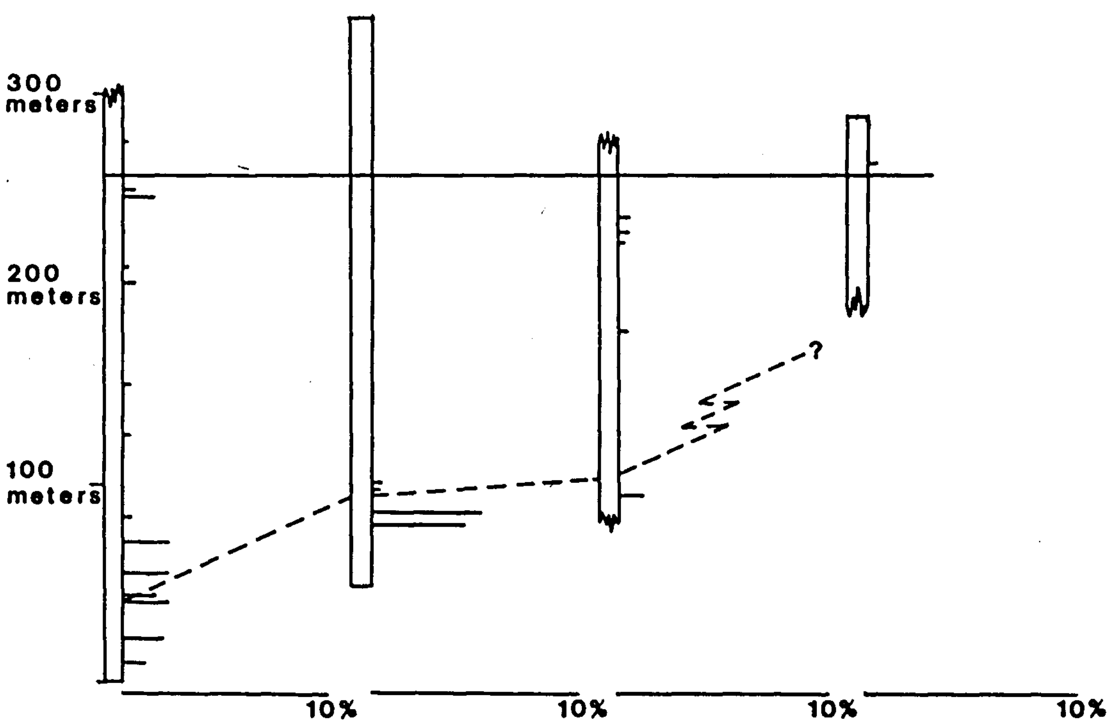
Present only at specific horizons (Figure 11), calcite occurs in only 46 percent of the transition zone samples and averages 0.56 percent by volume, statistically less than the average of 1.9 percent by volume found in the Mauch Chunk Formation ($F = 3.70$, df treatment= 2, df error= 3, critical F at 95 percent level= 3.28). Calcite is a normal constituent of the Mauch Chunk and is present in 100 percent of the samples studied. Plagioclase feldspar, which occurs consistently throughout the Mauch Chunk Formation, is not normally part of the compositional make-up of the transition zone, and is present in trace amounts in only 3 transition samples (Figure 20). Plagioclase is entirely absent from the Pottsville samples

Figure 20 - Distribution of plagioclase feldspar and opaques in the transition zone, in the immediately subjacent Mauch Chunk, and in the superjacent Pottsville Formation.

PLAGIOCLASE



OPAQUES



investigated. A one-way analysis of variance at the 95 percent confidence level shows that the transition zone sandstones statistically resemble those of the Pottsville Formation ($F= 0.54$, df treatment= 1, df error= 29, critical $F= 4.18$), and is unlike the Mauch Chunk Formation with respect to the quantity of plagioclase feldspar ($F= 21.6$, df treatment= 1, df error= 30, critical $F= 4.17$). Opaque minerals, occurring mostly as matrix material or as a few individual crystals, are present in 100 percent of the Mauch Chunk samples, but are rare to absent in those sandstones of the transition and Pottsville sections (Figure 20). Detrital matrix is consistently present at an average of 1.5 percent by volume in the Mauch Chunk Formation, while only traces of true matrix material occur in the transition and Pottsville Formation. The Pottsville Formation and transition rocks exhibit a few quartz grains with inclusions of rutile; rutilated quartz is nonexistent in the Mauch Chunk underlying the transition zone.

The similarity between the transition and Pottsville conglomerates with respect to their pebble suites is evident in Figure 15. Both are oligomictic and are comprised mostly of stable vein quartz pebbles.

The red shales of the transition zone are compositionally similar to those shales in the underlying Mauch Chunk; in both, illite and chlorite are the dominant clays. Unlike the transition and Mauch Chunk shales, the Pottsville shales contain no chlorite clays.

From the above evidence and stratigraphic work of others (Wood et al, 1962; Edmunds et al, 1979), it is concluded that the transition zone is not a unique rock suite nor an exclusive member of the Mauch Chunk or Pottsville Formations, but an intertonguing of the basal Pottsville and upper Mauch Chunk rocks. In addition, no petrographic stratigraphic marker that might be used as a basis for a sharp Mauch Chunk-Pottsville contact can be established. Assignment of the contact between the Mauch Chunk and Pottsville is purely an arbitrary decision.

Depositional Model

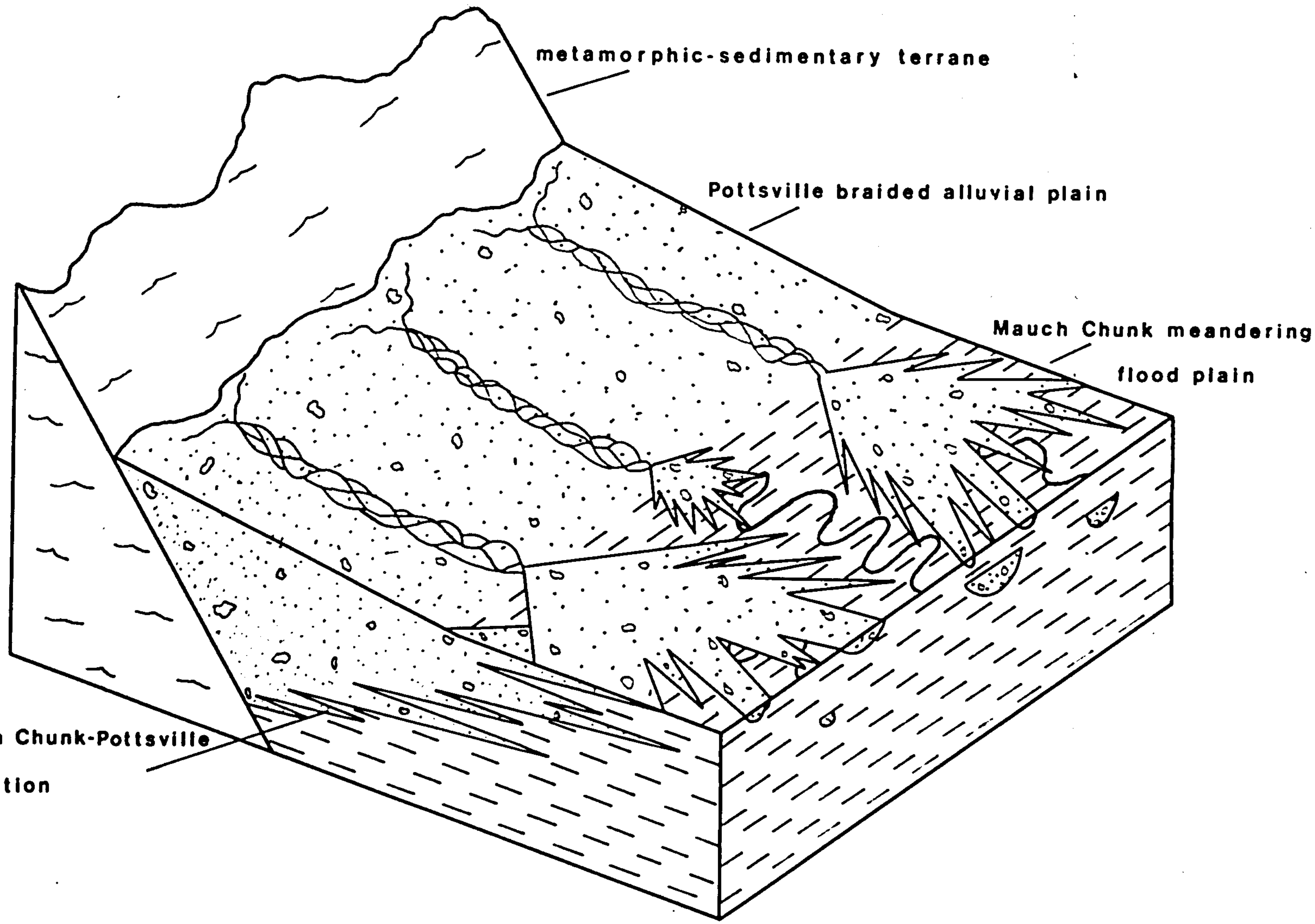
Rocks of the Mauch Chunk-Pottsville transition zone appear to represent an episodic change in depositional conditions from that of dominantly relatively low energy to that of relatively high energy in an above sea level basin of deposition. Such a change can be explained by renewed uplift, possibly episodic, in the source area or further downwarping of the depositional basin or both.

Hoque (1968), on the basis of a paleocurrent study of the Mauch Chunk Formation, described its environment of deposition as that of a large prograding fluvial deltaic complex. He concluded that facies representing a deltaic front and a large deltaic plain with meandering streams and extensive flood plains are present in the Mauch Chunk deposits. Sediment dispersal data, the characteristic red color of the rocks, the presence of fine-grained laminated and crossbedded sandstones, and extensively finely laminated shales containing mudcracks and rain imprints, and the lack of marine fossils were used by Hoque (1968) to support his conclusions.

The Pottsville Formation is made up of clastic deposits representing high energy deposition of recycled sediments by braided streams on a large alluvial plain (Meckel, 1967). Meckel (1967) reports that the Pottsville is a westward thinning, wedge-shaped complex of beds consisting primarily of coarse, poor- to well-sorted sandstones and conglomerates. He describes the large range in size of clasts (up to greater than 125 millimeters in diameter), the high degree of rounding, the compositional maturity of the sediments, the numerous shallow cut and fill channels, and the lenticular nature of the interbedded conglomerates. All of this, plus the Early Pennsylvanian encroachment of the Pottsville sediments over the Mauch Chunk delta suggest renewed tectonic activity in the source area.

Figure 21 graphically illustrates the progradation of the Pottsville material over that of the Mauch Chunk and the transition zone thus formed. Pottsville sediments were transported and reworked by braided streams moving down a relatively steep gradiant on an alluvial plain

Figure 21 - Graphic representation of transition zone depositional system.


metamorphic-sedimentary terrane
Pottsville braided alluvial plain
Mauch Chunk meandering flood plain
Mauch Chunk-Pottsville transition

and were eventually prograded onto gently graded flood plains of the Mauch Chunk delta.

Shale layers in the transition zone and the immediately subjacent red sandstones in the Mauch Chunk represent flood plain and meandering stream conditions during deposition. The fine-grained, well-sorted and crossbedded Mauch Chunk sandstones are characteristic of sand deposits in meandering streams (Selley, 1978). Flood plain deposition is concluded for the transition shales due to: 1) their red color, which according to Walker (1967), suggests oxidizing conditions as a result of subaerial exposure and periodic wetting; 2) the finely laminated nature and the presence of silty zones in many of the shales (Reineck, Singh, 1975; Reading, 1978), and 3) the occurrence of mudcracks and plant debris indicating subaerial exposure (Reading, 1978). The carbonate concretions existing in some of the shales may have resulted from high evaporation (Reineck, Singh, 1975) during subaerial exposure.

High energy alluvial channel deposition of reworked sediments in the transition sandstones and conglomerates is suggested by their characteristically shallow lenticular and wedge-shaped interbedding and the presence of clast supported, well-rounded conglomerates (Walker, 1975). Reworking by streams has winnowed out much of the clay and silt-sized material in these conglomerates. The high energy nature of these flows is also indicated in the basal contact of the gray horizons as evidence of scour into the red shales and by the inclusion of red shale rip-up clasts in the sandstones and conglomerates.

Large tabular beds of matrix supported conglomerates lacking fabric and sedimentary structures indicate the possibility of debris type flow (Bull, 1972; Walker, 1975). Unlike normal fluviatile deposition, the matrix is not winnowed out since all the sediment is effectively "dumped" into place.

During the initial stages of Pottsville encroachment, streams most likely carried material rapidly off the steeper slope and subsequently formed splays of alluvium on the Mauch Chunk flood plain (Figure 21).

Further progression of Pottsville deposition caused the coarse alluvial material to eventually "choke" off the Mauch Chunk muds. This is suggested by the stratigraphically upward thickening sandstones and thinning shales in the transition sections. Splaying may have been encouraged by the sudden release of Pottsville material from minor catchment basins of unknown origin near the margin of the main depositional basin. In addition, since the region was subject to humid conditions, periodic rains may have lowered the viscosity of the advancing alluvium enough to cause sudden flowage onto the flood plain.

Red Beds

The problem of the genesis of red beds is controversial and is beyond the scope of this project. Nevertheless, it is herein suggested that the red coloration may have been caused by both in situ and detrital processes.

The red color of the transition shales may be due to in situ oxidation of interlayered iron present in the chlorite clays. This is proposed on the basis of the change from red shales containing chlorite in the transition rocks to gray shales containing no chlorite in the Pottsville formation. The flood plain environment is an oxidizing environment.

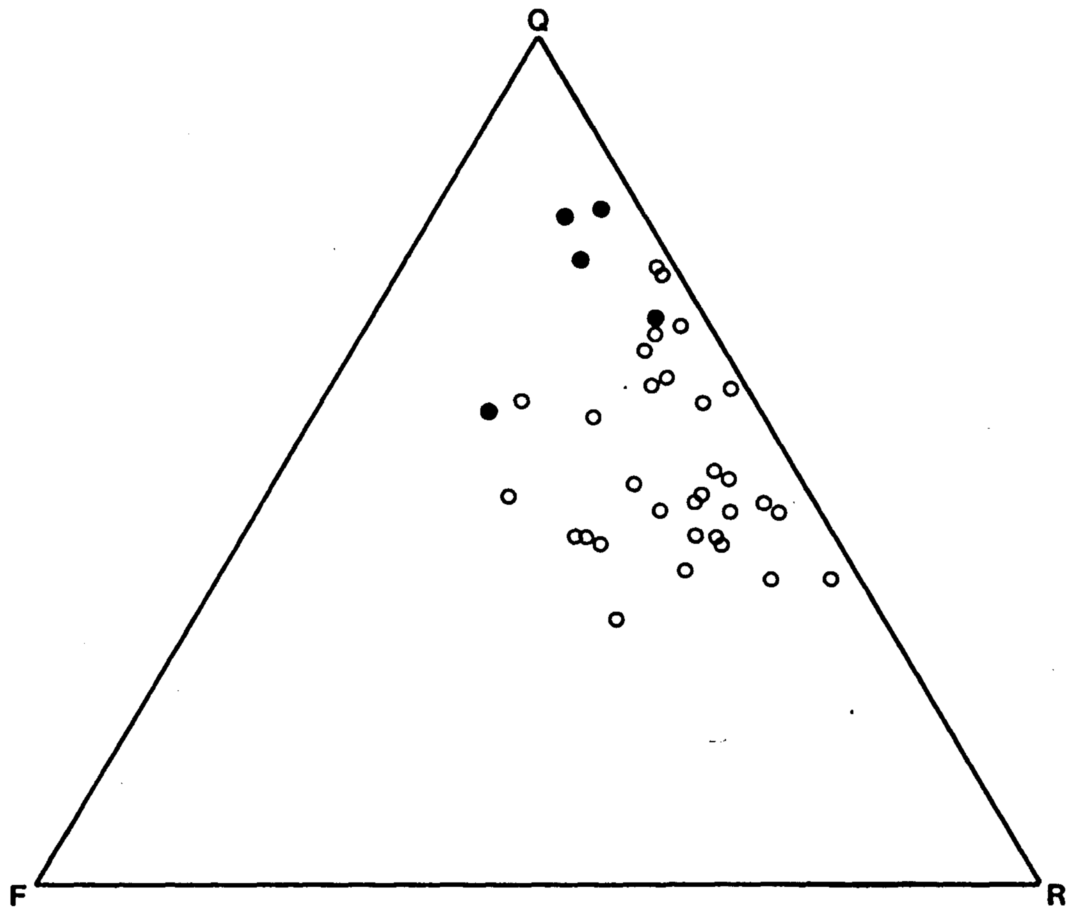
It is possible, however, that oxidation occurred during transport or that the red coloring was brought in by already oxidized material. Van Houten (1968) points out that further in-place oxidation of transported material may be important, especially in thick red rocks, from sedimentary type sources. Ferric oxides, in the form of detrital hematite, are commonly brought in from the erosion of lateric soils, which are characteristic of low latitude tropic and subtropic climates (Van Houten, 1961, 1968). Edmunds et al (1979) suggest that the Carboniferous rocks in Pennsylvania were deposited in such a climate. Hoque (1968) reports that the red color in the Mauch Chunk sandstones is due to the presence of hematite in the matrix material. Very little detrital hematite was observed in the samples from this study suggesting that the pigmentation is most likely the result of biotite alteration to hematite (Figure 17) or the oxidation of iron in other ferrous minerals.

Provenance

The data herein reported and those of other authors indicate that the origin of the transition zone sediments was an uplifted source southeast of the study area. This source consisted mostly of metasedimentary and sedimentary strata of schists, phyllites, and argillites with minor amounts of intercalated igneous and hydrothermal material. Paleocurrent studies by Meckel (1967) and Hoque (1968) show the southeastern source. Edmunds et al (1979) also indicate a southeastern source.

If this is true, rocks most distal to the source (in this study, the northern-most section in the Wyoming-Lackawanna Basin) should display a compositionally more mature framework; in other words, they should become more quartzitic due to the winnowing out of the labile constituents during the relatively longer sediment transport (Folk, 1974). Figure 22 shows that the rocks from the Wyoming-

Figure 22 - Ternary diagram showing the more quartzitic (less lithic) nature of the Wyoming-Lackawanna samples. Q-monocrystalline and vein quartz, R-lithic fragments including quartzite and chert, F-feldspars.



●-Wyoming-Lackawanna samples

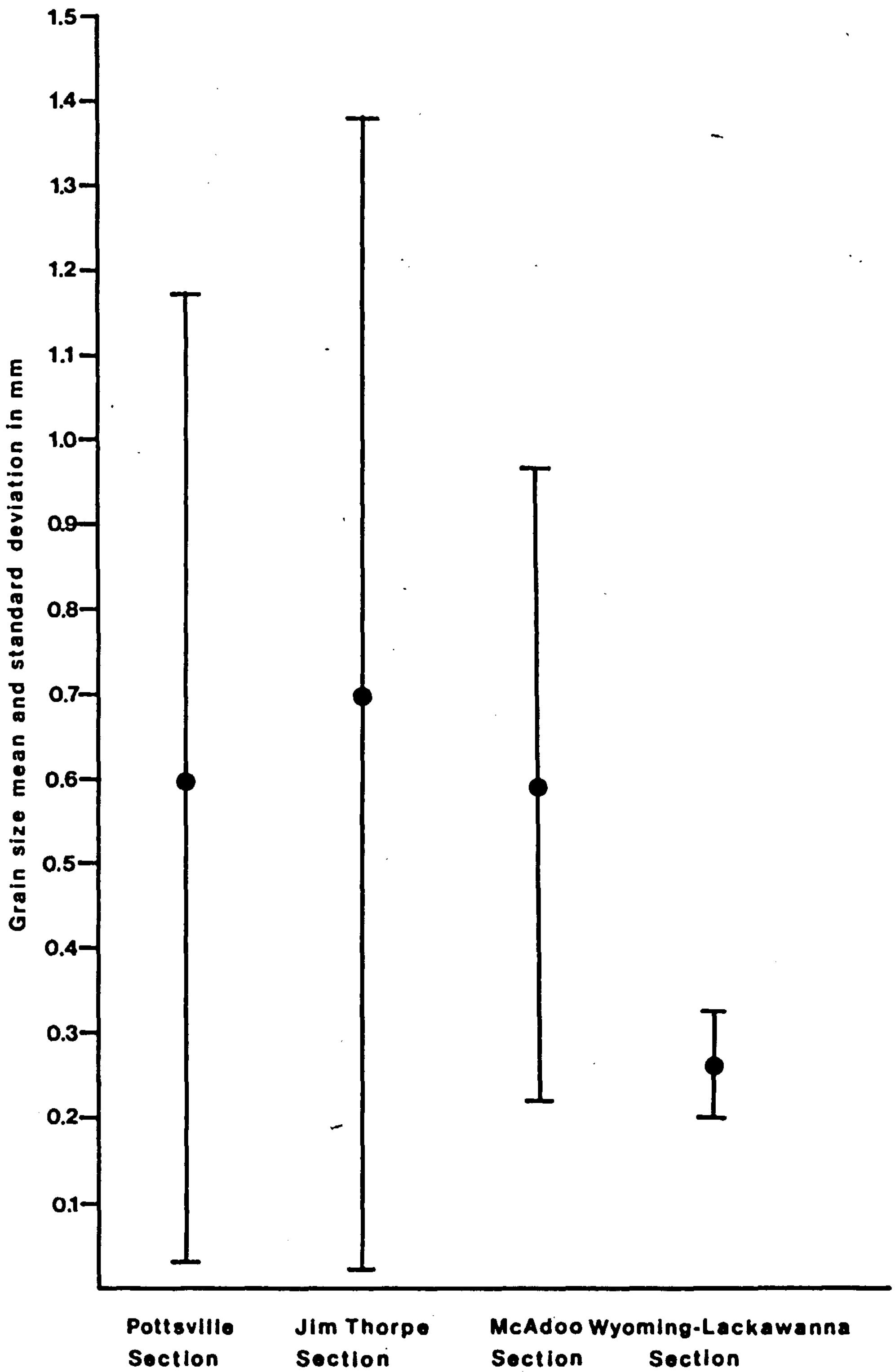
O-Pottsville, McAdoo and Jim Thorpe samples

Lackawanna Basin are, in fact, generally more quartzitic than those from the other more proximal sample areas. This is compatible with a southeastern source. In order to better illustrate this comparison, quartzite is included in the rock fragment pole rather than the quartz pole due to its greater susceptibility to disaggradation during transport relative to monocrystalline quartz.

Similarly, the distal rocks in the Wyoming-Lackawanna Basin should be better sorted and have a generally finer sand-sized fraction due to weathering and disaggregation of larger material over the longer distance of transport. Figure 23 clearly illustrates the better sorting and finer grain size of the Wyoming-Lackawanna rocks.

The abundance of quartz and phyllitic, schistose, and argillaceous rock fragments strongly suggest a dominantly metasedimentary and sedimentary source area (Graham et al, 1976; Moore, 1979). In addition, the larger well-rounded grains that are present indicate the presence of sedimentary strata in the source area (Moore, 1979). A low percentage of

Figure 23 - Plot of average grain size and sorting of each measured section.


Grain size mean and standard deviation in mm
1.5
1.4
1.3
1.2
1.1
1.0
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
Pottsville Section
Jim Thorpe Section
McAdoo Section
Wyoming-Lackawanna Section

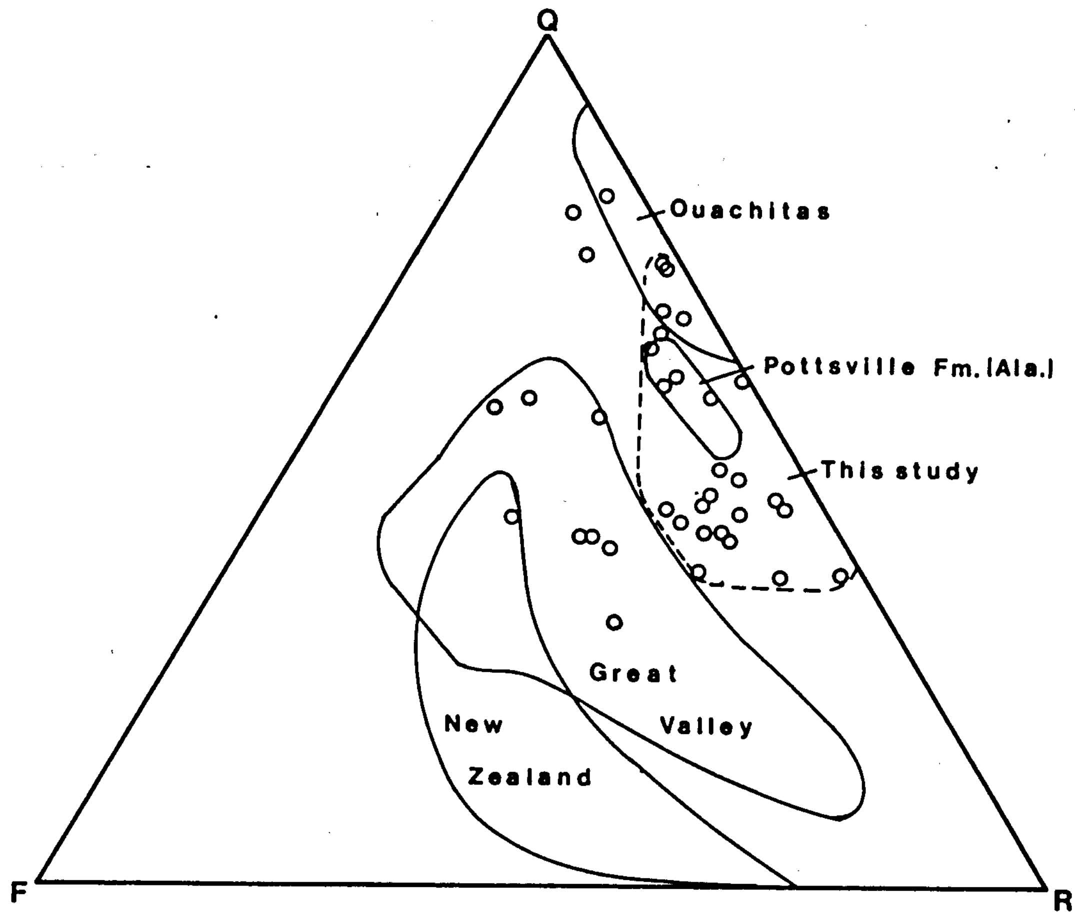
feldspar is consistent with a metasedimentary source terrane as opposed to dominantly plutonic and volcanic provenances (Pettijohn, 1972; Folk, 1974; Graham et al, 1976). The heavy mineral suite in the transition sandstones also suggests metasediments in the source area.

The occurrence of, and the positive correlation between, the amounts of chert and calcite indicate the exposure of carbonate rock in the source area.

Figure 24 illustrates how the main clustering of the transition rocks plotted on a quartz-rock fragment-feldspar (QRF) diagram closely compares with clusterings of the quartz and metasedimentary rich Ouachita and Pottsville rocks (Alabama), which are both from known metasedimentary origins (Graham et al, 1976). Rocks from plutonic and volcanic sources contain more volcanic rock fragments and a significantly greater amount of feldspathic material.

Certain quartz grain characteristics of transition zone sandstones can also be used as provenance indicators. These characteristics include crystal shape, inclusions, extinction angles, and degree of

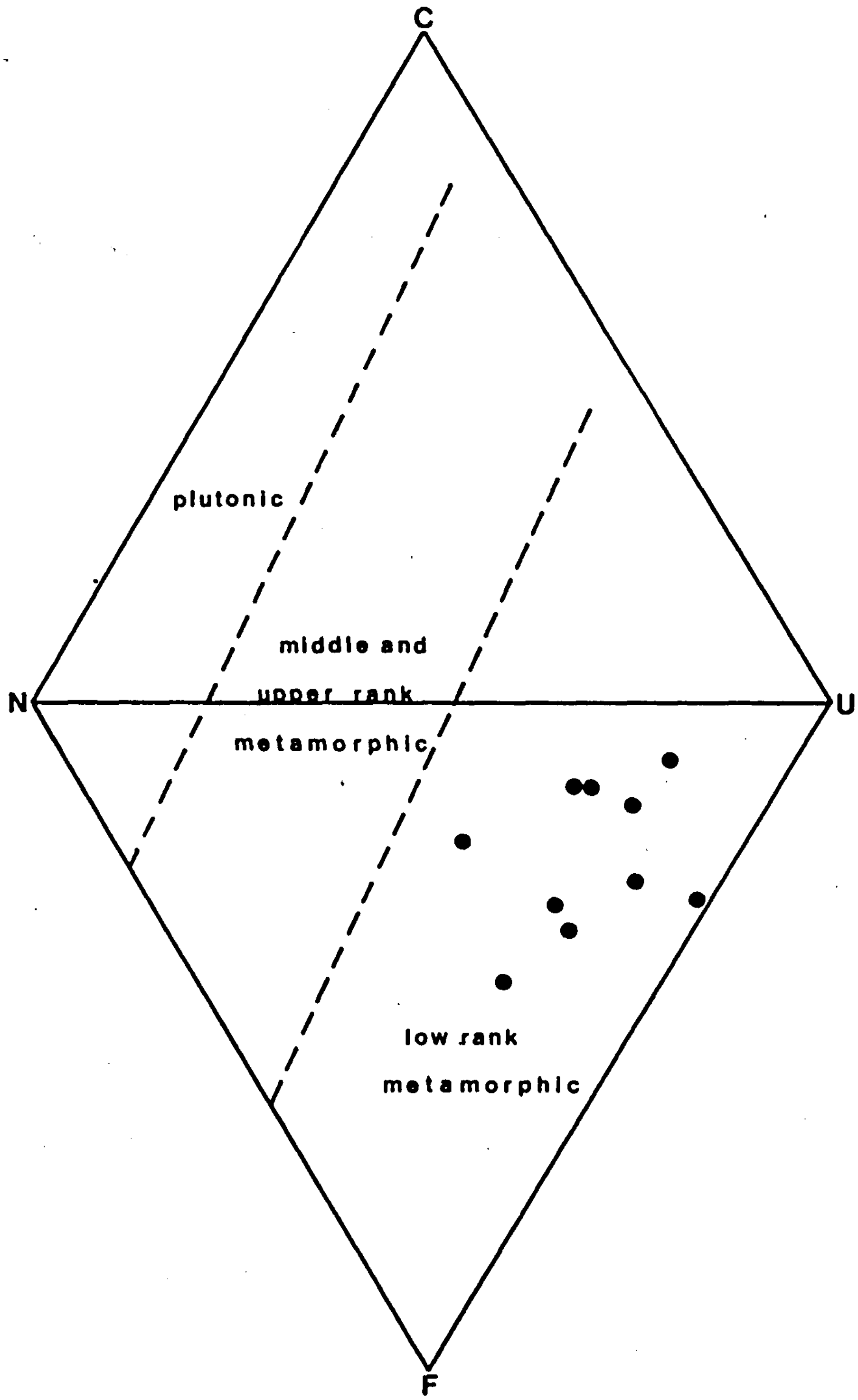
Figure 24 - Ternary diagram comparing detrital modes of sandstones from this study with those from volcano-plutonic origins (Great Valley, Dickinson and Rich, 1972; New Zealand, Dickinson, 1971) and metasedimentary origins (Pottsville in Alabama and Ouchita rocks, Graham et al, 1976). Q-mono- and polycrystalline and vein quartz, R-lithic fragments including chert, F-feldspars.


Q
Ouachitas
Pottsville Fm. (Ala.)
This study
Great
Valley
New
Zealand
F
R

polycrystallinity. The presence of elongated and bimodal polycrystalline grains, especially those containing mica flakes, is diagnostic of schists and other medium- to low-grade metamorphic rocks (Blatt, Middleton, and Murry, 1972; Folk, 1974). Rutilated quartz may be indicative of both igneous and metasedimentary origins, but it is most likely a result of the occurrence of minor amounts of granitic material (Blatt, Middleton, and Murry, 1972; Folk, 1974). Since rutilated quartz occurs only in the younger transition rocks and not in the Mauch Chunk, it is possible that erosion caused a later uncovering of plutonic material in the source area. The vein quartz and vermicular chlorite inclusions are supportive evidence for the subordinate amounts of hydrothermal source material (Folk, 1974).

Many workers have considered the relative amounts of polycrystallinity and undulatory extinction in quartz as possible diagnostic evidence for interpreting the general composition of source terrane. Blatt and Christie (1963) stated that polycrystalline and undulatory quartz are inconclusive for determining source types due to their abundance in both igneous and metamorphic regions. However, they do claim that sandstones from extrusive origins yield high proportions of nonundulatory quartz. Basu et al (1975) believe that quartz type is suggestive of provenance; they have devised a scheme (Figure 25) that, on the basis of relative amounts of undulatory and nonundulatory quartz, polycrystalline quartz, and polycrystalline quartz with 2 - 3 individuals or greater than 3 individuals, indicates whether individual quartz grains are derived from low-, medium-, or high-grade metamorphic or plutonic sources. Their findings are based on 8,000 counts of mono- and polycrystalline quartz grains in over 200 samples with supposedly known origins. They concluded that in sand-sized material: 1) the proportion of polycrystalline grains increases as the grade of metamorphism in the source decreases; 2) the polycrystalline quartz from plutonic and high rank metamorphic origins is coarse-grained; 3) finer-grained polycrystalline

Figure 25 - Four variable plot after Basu et al (1975) showing nature of quartz population in 10 transition zone sandstone samples. N-nonundulatory quartz, U-undulatory quartz, F-greater than 75 percent of polycrystalline grains have more than three individuals, C-greater than 75 percent of polycrystalline quartz grains have two or three individuals.


C
N
U
F
plutonic
middle and
upper rank
metamorphic
low rank
metamorphic

material is derived mostly from low rank metamorphic sources, and 4) undulatory quartz dominates detritus from lower rank metamorphic terrane since higher grades of metamorphism encourage recrystallization resulting in straight extinction in the new growths (Folk, 1974; Young, 1976).

The relative proportions of these quartz types as shown in Figure 25 clearly indicate that the transition rocks are derived from low rank metamorphic (i.e. metasedimentary) material. Points were plotted by first determining if they should be located in the upper or lower triangle. If greater than 75 percent of the polycrystalline quartz in a sample contains more than 3 individuals, the point will fall into the lower triangle. It will plot in the upper triangle if less than 75 percent of the grains contain more than 3 crystals. Where the point lies within its appropriate triangle depends on the relative percentages of undulatory (greater than 5 degrees stage cover sull sweep of extinction), nonundulatory (less than 5 degrees stage rotation to cover full sweep of extinction), and polycrystalline quartz.

Certain restrictions and cautions are necessary with use of this diagram. All data must be taken from sand-sized material because quartz is most stable within this size fraction (Blatt, Middleton, and Murry, 1972; Basu et al, 1975) and because counting polycrystalline grains over a large range in size may bias the crystal number per grain data. The determination of undulostisity on a flat stage may produce an error factor due to misalignment of quartz grain c-axes with the plane of the thin section (Basu et al, 1975). Blatt and Christie (1963) claim that because of these constrictions, such classification is meaningless; however, Basu et al (1975) concluded, after measuring extinction angles with both a universal stage and a flat stage, that the error produced is small enough to warrant the use of a flat stage in routine petrographic studies.
Finally, since undulatory quartz can result from post-depositional stresses due to folding, faulting, and/or lithostatic pressure, a possible over-estimation of undulose grains actually reflecting the type of source terrane may result. However, sand-

stones containing abundant labile rock fragments can reduce this error since the soft fragments absorb and direct much of the post-depositional stress away from the harder quartz (Blatt and Christie, 1963; Basu et al, 1975). Blatt and Christie (1963) also feel that post-depositional undulostisity is not a widespread phenomenon.

The metasedimentary source is compatible with a continental collision model, which caused crustal uplift along a suture belt as opposed to a magmatic arc model, which results in characteristically more plutonic and volcanic source terranes. (Graham et al, 1976).

Diagenetic Changes

Grain Contacts

Diagenetic processes can be defined as those which occur in crustal conditions with temperatures ranging from 0 to 200°C. and depths from 0 to 6000 meters (Blatt, 1979). Evidence observed in the transition rocks indicates that they have undergone diagenetic changes within these temperature and pressure limits.

The diagenetic features present fall into two broad categories: 1) compaction features due to lithostatic pressures, including crushed and deformed rock fragments and distorted grain contacts, and 2) authigenic precipitates and replacement features that include calcite cement, quartz overgrowths, calcite replacing both quartz and plagioclase feldspar, clay bonding to quartz, and the sericitization of feldspar. The fundamental consequence of these changes are lithification and loss of porosity.

The most obvious compaction features occurring throughout the transition zone are the crushed and deformed ductile rock fragments that occupy pore space (Figure 9B). Rock fragment deformation, sometimes referred to as solid flow (Taylor, 1950), is a result of overburden pressures and pressures due to folding. Deformity ranges from barely deformed grains to "wisps" of fragmented material squeezed between packed framework grains. The resulting pseudomatrix is responsible for high losses of porosity, especially in the initial stages of compaction (Pettijohn, 1972; Burns and Ethridge, 1979). The significance of porosity loss due to grain deformity is directly proportional to the abundance of lithic fragments (Blatt, 1979).

When sands are first deposited, the grains exhibit mostly point-to-point and straight contacts, but some long and concave-convex boundaries, depending on the shape of the grains involved, can also occur (Taylor, 1950). These contacts later become distorted to varying degrees due to rearrangement or recrystallization caused by compaction. The result is a higher proportion of long, concavo-convex contacts, as well as sutured and irregular contacts in the lithified rock and, in cases of higher pressures, microstylolites (Sloss and Feray, 1948) may form (Figure 13).

Taylor (1950) assessed the degree of pressure effects upon sandstones by classifying types of grain contacts based on the severity of distortion. Sandstones exhibiting mainly tangential and some long and concavo-convex grain boundaries have been subjected to a minimum of pressure; whereas, samples with mostly long, concavo-convex, and sutured contacts indicate the effects of greater depths and pressure. She believes that long contacts are dependent mainly on the shape of the grains during compaction or on the yielding of soft fragments against straight edges of more competent grains. Therefore, care must be exercised when evaluating long contact genesis. Concavo-convex boundaries are caused by the differential yielding of grains with curved surfaces, or they are a result of grain interpenetration caused by pressure solutioning at points of grain contact. They are especially common between quartz grains and soft rock fragments. Suturing is caused by local pressure solution along grain contacts. Taylor (1950) also showed that with increasing depth of burial: 1) the number of grain contacts increased; 2) the number of tangential contacts rapidly dropped until they disappeared at a depth of about 2000 meters; 3) long contacts predominated at most depths, but their abundance was highest around 1400 - 1700 meters; 4) concavo-convex boundaries displayed the greatest abundance at a depth of approximately 2100 meters, and 5) sutured contacts did not appear until

1500 meters. The rocks in this study exhibit mostly long, concavo-convex, and sutured contacts. In addition, a few microstylolites were observed. Thus, it can be presumed that the transition rocks reached burial depths of only a few thousand meters. Only general inferences can be made regarding burial depths since these rocks have been subjected to intense regional folding, which also influences pressure effects and grain boundary distortion.

Cementation

Calcite and quartz are the two types of authigenic cements occurring in the transition rocks. Calcite occurs as large, single or composite pore-filling crystals surrounding framework grains or as small micritic patches filling interstices. In places, the cement has disrupted the framework resulting in few grain-to-grain contacts with the production of a "floating" grain texture. Folk (1965) refers to this phenomenon as "displacement precipitation". Displacement precipitation implies lack of overburden and/or early diagenetic cementation (Folk, 1974;

Galloway, 1979).

Dapples (1972) refers to calcite as an incompatible cement in sandstones with a dominantly quartz grain framework because of the difference in composition. He states that calcite cementation contributes to lithification by "gluing" effects based on the adhesion properties of the cement and on the irregularity of contact boundaries with the surrounding grains. Adhesion along irregular contacts is greater than that found on smooth grain boundaries.

Calcite, where present, has usually reacted with quartz and has caused from very slight to severe etching and erosion of the quartz (Figure 12A). The highly etched boundaries and inclusions of quartz in contact with calcite is evidence that the calcite is replacing quartz (Pettijohn, 1972). The irregular boundaries and bonding effects of the replacement play an important role in the lithification of the rock.

Various explanations have been offered regarding the cause of quartz replacement by calcite.

Walker (1962) emphasized the relationship between the solubility of calcite and pH, especially at values of 9 or above. Calcite solubility decreases markedly at pH values above 9, such that dissolution of silica by calcite can take place in this range.

Changes in the partial pressures of CO_2 can cause changes in pore water pH values; however, the mechanisms for varying the partial pressure of CO_2 in buried rocks is not well understood (Pettijohn, 1972). Dapples (1972) indicates that variations in the partial pressure of atmospheric CO_2 near an outcrop may effect pH values in the rock. He also states that this is only a minor surface related phenomenon.

Variations in calcite solubility are also a function of temperature change (Blatt, 1979). The solubility of both calcite and quartz increase with rising temperatures associated with depth of burial. Furthermore, the solubility of calcite increases at a slower rate relative to that of quartz; therefore, the result is dissolution of the quartz by the calcite. Degens (1965), however, believes that, given a constant partial pressure of CO_2, the solubility of calcite actually decreases with rising temperatures, also resulting in the replacement of silica by calcite. These mechanisms are most effective at relatively greater depths of burial. Temperature variation is probably the best explanation for calcite-quartz replacement in the transition rocks. Replacement caused by high pH values seems unlikely since values above 9 are rare in natural environments (Pettijohn, 1972).

The occurrence of calcite replacing plagioclase feldspar is also an indicator of varying pH values or changes in the relative solubility of silica versus calcite with temperature (Dapples, 1967).

Waldschmidt (1941), Pettijohn (1972), and Blatt (1979) suggest that the source of calcite cement is a precipitate from supersaturated connate or meteroic pore water with respect to calcite. These authors and Scholle (1979) point out the dissolution of carbonate shell fragments as an additional source. Pressure solution of detrital carbonate may be a source (Dapples, 1971, and Pettijohn, 1972). Scholle (1979) claims that scattered shell fragments lead to poikiolotopic textures; however, Dapples (1971) states that the origin of these textures is not well understood.

The writer believes that although early precipitation from meteroic waters is a possible source of the calcite, precipitation following pressure solution of detrital carbonate at depth is the most likely explanation for the origin of calcite cement. The presence of sparry cement in some specimens suggests "displacement precipitation", and the rocks' continental origin indicate possible precipitation from meteroic waters. Connate water and shell fragments are more characteristic of marine environments. However, the strong correlation between calcite cement and altered carbonate grains is convincing evidence that the carbonate grains provided calcite for cementation. The sporadic distribution of the cement may be explained by lack of pore water circulation due to low porosities characteristic of the compaction and burial of lithic arenites. Alteration of the calcite detritus may be a result of pressure solution.

Silica cementation present in the transition rocks is evidenced by the secondary quartz overgrowths and interlocking quartz grains. Overgrowths are difficult to observe, since tracers such as inclusions and dust rims that outline the original grain boundaries are generally lacking. Interlocking grain boundaries in sedimentary rocks generally are interpreted as a result of reprecipitation of secondary quartz following pressure solution of the original detritus (Dapples, 1972).

Three explanations for quartz grain overgrowth are: 1) precipitation from circulating silica saturated pore waters in highly porous sands (Blatt, 1979), 2) pressure solution at points of grain contact, and 3) silica liberation from quartz grains during their replacement by calcite (Moore, 1979). Since precipitation by pore water is restricted to clean (quartzose) shallow sands and silica replacement by calcite is not widespread in these rocks, the most likely origin of the secondary quartz in the transition zone is that the silica was removed by pressure solution following burial. The solubility of quartz rises at points of grain contact due to lithostatic pressures high enough to cause solution of the silicate. The dissolved quartz moves to the pore spaces (i.e. "pressure shadows"), where, due to lower pressure, its solubility drops and the dissolved quartz reprecipitates as overgrowths. Arguments against pore water circulation as a source of secondary silica are presented by Pettijohn (1972), and Blatt (1979), and include the fact that an enormous amount of water is needed to precipitate even very small quantities of quartz and the lack of buried lithic sandstones inhibits such circulation.

As overgrowths continue to grow, compound grains develop following a process described by Dapples (1972). According to Dapples, the compatible, thus stable overgrowths, grow until they come in contact with overgrowths from adjacent grains. These contacts tend to be unstable and are subject to recrystallization and grain interpenetration, including suturing and sometimes the formation of microstylolites, which results in a composite of interlocked grains. Although compound grains are undoubtedly a consequence of burial, Pettijohn (1972) points out that little is known regarding the relation between the compounding of grains and the amount of time and depth of burial needed for their formation. Not all overgrowths are associated with compound grains and some are relatively isolated. Such occurrences may be formed from reworked quartz grains with overgrowths (Scholle, 1979).

Stages and Sequence of Diagenetic Events

Wolf and Ciligariam (1976) summarize various classifications of diagenetic stages as functions of temperature and depth conditions. The classification used for this study is that described by Dapples (1962, 1967), which relates temperature and depth of burial conditions to mineral associations, intergrowths, and replacements. Dapples outlines three stages as follows: 1) Redoxomorphic (early stage of diagenesis)--this stage groups diagenetic processes that occur in loosely packed sands during deposition and very early burial. It is dominated by oxidation and reduction reactions, such as the oxidation of iron to form hematite and by the initial compaction of the framework characterized by shifting of grains and loss of porosity. All lithified rocks have at least passed through this stage; 2) Locomorphic (intermediate stage of diagenesis)--the processes described in this group are dominated by in situ precipitation of authigenic minerals, and mineral replacement and intergrowth. Examples of locomorphic changes include the production of silica and calcite cement and quartz and feldspar replacement by calcite, and 3) Phyllomorphic (late stage of diagenesis)--this stage, indicating deep burial is dominated by the alteration of clays, especially to muscovite and is the predecessor of the earliest stages of metamorphism.

The presence of calcite and quartz cements and quartz and feldspar replacement by calcite, suggest that the transition sandstones have at least reached the locomorphic stage, indicating possible depths of burial of at least several hundreds of meters, and possibly to significantly over a thousand meters. Pettijohn (1972) reports that the presence of these cements together with evidence of pressure solution indicate a depth of burial of over 1000 meters.

Stratigraphic work by Wood et al (1956, 1969) show that near the Pottsville measured section, the Pottsville and Llewellyn Formations overlying the transition zone reach an aggregate thickness of 1400 - 1500 meters. Assuming the probable lack of post-Pennsylvanian deposition in the area, the transition rocks were buried at least to approximately this depth. This is compatible with those depths predicted by the diagenetic evidence.

These rocks have been subjected to intense folding, which can induce additional pressure and subsequently additional diagenetic changes. Caution must therefore, be exercised when interpreting depths of burial from diagenetic evidence in folded rocks; otherwise, overestimation of burial depths may be made. The estimated depth of burial suggested in this paper, therefore, is a maximum depth of burial.

CONCLUSIONS

1) The transition zone sandstones and conglomerates are petrographically similar to the superjacent Pottsville sandstones and conglomerates. They are significantly different from those sandstones occurring in the subjacent Mauch Chunk Formation. The shale layers in the transition zone are lithologically and mineralogically similar to the Mauch Chunk shales and are unlike those shales studied in the Pottsville Formation.

2) The transition zone represents intertonguing of the Mauch Chunk and Pottsville Formations. Because no petrographic stratigraphic marker can be established, assignment of the Mauch Chunk-Pottsville contact is arbitrary.

3) The transition zone rocks (as well as the underlying Mauch Chunk and the overlying Pottsville) are part of the Appalachian continental clastic wedges that formed during the late Paleozoic. They were deposited by progradation of the alluvial Pottsville type material onto flood plain muds of the

older Mauch Chunk deltaic complex. The transition zone is therefore time transgressive. The transition rocks appear to represent an episodic change from relatively high energy to relatively low energy conditions of deposition. The Pottsville alluvial sediments occupy erosional channels cut into the Mauch Chunk muds.

4) The transition zone sediments had a southeasterly source that consisted primarily of metasedimentary and sedimentary strata with minor amounts of intercalated igneous and hydrothermal material.

5) Diagenetic evidence suggests that the transition zone rocks reached a maximum burial depth of over 1000 meters which is comparable with the 1400-1500 meter aggregate thickness of the overlying Pottsville and Llewellyn Formations.

REFERENCES

Barrell, J., 1907, Origin and significance of the Mauch Chunk shale: Geol. Soc. America Bull., V. 18, p. 449-476.

Basu, A., Young, S. W., Suttner, L. J., James, W. C., Mack, G. H., 1975, Re-evaluation of the use of undulatory extinction and polycrystallinity in detrital quartz for provenance interpretation: Jour. Sed. Petrology, V. 45, p. 873-882.

Blatt, H., 1979, Diagenetic processes in sandstones: Soc. Econ. Paleontologists Mineralogists Spec. Pub., No. 26, p. 141-157.

__________, and Christie, J. M., 1963, Undulatory extinction in quartz of igneous and metamorphic rocks and its significance in provenance studies of sedimentary rocks: Jour. Sed. Petrology, V. 33, p. 559-579.

__________, Middleton, G. V., and Murray, R. C., 1972, Origin of sedimentary rocks: Englewood Cliffs, N.J., Prentice-Hall, 634 p.

Bull, W. B., 1972, Recognition of alluvial-fan deposits in the stratigraphic record, in Recognition of ancient sedimentary environments: Rigby, K. J., Hamblin, W. K., eds., Soc. Econ. Paleontologists Mineralogists Spec. Pub., No. 16, p. 68-83.

Burns, L. K., and Ethridge, F. G., 1979, Petrology and diagenetic effects of lithic sandstones: Paleocene and Eocene Umpqua Formation, southwest Oregon: Soc. Econ. Paleontologists Mineralogists Spec. Pub., No. 26, p. 307-317.

Dapples, E. C., 1962, Stages of diagenesis in the development of sandstones: Geol. Soc. America Bull., V. 73, p. 913-934.

________________, 1967, Diagenesis of sandstones, in Larson, G., and Chilingar, G. V., eds., Diagenesis of sandstones: Developments in sedimentology, V. 8, Elsevier, New York, p. 91-125.

________________, 1971, Physical classification of carbonate cement in quartzose sandstones: Jour. Sed. Petrology, V. 41, p. 196-204.

________________, 1972, Some concepts of cementation and lithification of sandstones: Amer. Assoc. Petroleum Geologists Bull., V. 56, p. 3-25.

Degens, E. T., 1965, Geochemistry of sediments: A brief survey: Englewood Cliffs, N.J., Prentice-Hall, Inc., 342 p.

Dickinson, W. R., 1970, Interpreting detrital modes of graywacke and arkose: Jour. Sed. Petrology, V. 40, p. 695-707.

________________, 1971, Detrital modes of New Zealand graywackes: Sedimentary Geology, V. 5, p. 37-56.

________________, and Rich, E. I., 1972, Petrologic Intervals and petrofaces in the Great Valley sequence, Sacramento Valley, California: Geol. Soc. America Bull., V. 83, p. 3007-3024.

Dyson, J. L., 1954, Relation of stratigraphy and structure to uranium occurrences near Mauch Chunk, Pennsylvania: Proc. Pa. Acad. Sci., V. 28, p. 124-134.

Edmunds, W. E., Berg, T. M., Sevon, W. D., Piotrowski, R. C., Heyman, L., and Rickard, L. V., 1979, The Mississippian and Pennsylvanian (Carboniferous) systems in the United States - Pennsylvania and New York: U.S. Geol. Survey Prof. Paper 1110-B., 33 p.

Epstein, J. B., Sevon, W. D., Glaeser, J. D., 1974, Geology and mineral resources of the Lehighton and Palmerton quadrangles, Carbon and Northampton Counties, Pennsylvania: Pa. Geol. Surv. 4th Ser., Atlas 195 cd.

Folk, R. L., 1965, Some aspects of recrystallization in ancient limestones, in, Pray, L. C., and Murray, R. C., eds., Dolomitization and limestone diagenesis: Soc. Econ. Paleontologists Mineralogists Spec. Pub., No. 13, p. 14-48.

__________, 1974, Petrology of sedimentary rocks: Hemphill Publishing Co., Austin, Tx., 182 p.

Galloway, W. E., 1979, Diagenetic control of reservoir quality in arc-derived sandstones: Implications for petroleum exploration, Soc. Econ. Paleontologists Mineralogists Spec. Pub., No. 26, p. 251-262.

Gault, H. R., Dahlhausen, J. K., Yeakel, L., 1957, Note on a partial section of the Pottsville - Mauch Chunk transition near Jim Thorpe, Pennsylvania: Proc. Pa. Acad. Sci., V. 31, p. 114-119.

Grabau, A. W., 1906, Types of sedimentary overlap: Geol. Soc. America Bull., V. 17, p. 567-636.

Graham, S. A., Ingersoll, R. V., Dickinson, W. R., 1976, Common provenance for lithic grains in carboniferous sandstones from Ouachita Mountains and Black Warrior Basin: Jour. Sed. Petrology, V. 46, p. 620-632.

Hoque, M. U., 1968, Sedimentologic and paleocurrent study of Mauch Chunk sandstones, south-central and western Pennsylvania: Amer. Assoc. Petroleum Geologists Bull., V. 52, p. 246-263.

King, P. B., 1977, The evolution of North America: Princeton Univ. Press, Princeton, N.J., p. 42-68.

Klemic, H., 1962, Uranium occurrences in sedimentary rocks of Pennsylvania: U. S. Geol. Survey Bull., 1107D, p. 243-288.

__________, and Baker, R. C., 1954, Occurrences of uranium in Carbon County, Pennsylvania: U. S. Geol. Survey, circ. 350, 8 p.

__________, Warman, J. C., and Taylor, A. R., 1963, Geology and uranium occurrences of the northern half of the Lehighton, Pennsylvania quadrangle and adjoining areas: U. S. Geol. Survey Bull. 1138, 97 p.

Lesley, J. P., 1876, The Boyd's Hill gas well at Pittsburgh: 2nd Pa. Geol. Survey, Rpt. L, p. 217-237.

__________, d'Invilliers, E. V., Smith, A. D. W., 1895, A summary description of the geology of Pennsylvania - final report: 2nd Pa. Geol. Survey, V. 3, pt. 1, p. 1629-2153.

McCauley, J. F., 1957, Preliminary report on the sedimentary uranium occurrences in the state of Pennsylvania: Pa. Geol. Survey 4th Ser., Prog. Rpt. 152, 22 pp.

McKee, E. D., and Weir, G. W., 1953, Terminology for stratification and cross-stratification: Geol. Soc. America Bull., V. 64, p. 381-390.

Meckel, L. D., 1967, Origin of Pottsville conglomerates (Pa.) in the central Appalachians: Geol. Soc. America Bull., V. 78, p. 223-258.

__________, 1970, Paleozoic alluvial deposition in the central Appalachians: A summary, in Fisher, G. W., Pettijohn, F. J., Reed, J. C., Jr., Weaver, K. N., eds., Studies in Appalachian geology - central and south, New York, Wiley Interscience, p. 49-68.

Montgomery, A., 1954, Uranium minerals of the Mauch Chunk area, Pennsylvania: Pa. Acad. Sci. Proc., v. 28, p. 102-110.

Moore, G. F., 1979, Petrography of subduction zone sandstones from Nias Island, Indonesia: Jour. Sed. Petrology, v. 49, p. 71-84.

Pettijohn, F. J., 1957, Sedimentary rocks: Harper and Brothers, N.Y., 718 p.

________________, Potter, P. E., Siever, R., 1972, Sand and sandstone: Springer-Verlag, New York, 618 p.

Reading, H. G., ed., 1978, Sedimentary environments and facies: New York, Elsevier, 557 p.

Reineck, H. E., and Singh, I. B., 1975, Depositional sedimentary environments: Springer-Verlag, Berlin, 439 p.

Rodgers, H. D., 1858, The geology of Pennsylvania: 1st Pa. Geol. Survey, v. 1, 586 pp., v. 2, 1045 pp.

Scholle, P. A., 1979, A color illustrated guide to constituents, textures, cements, and porosities of sandstones and associated rocks: Am. Assoc. Petroleum Geologists Mem. 28, 201 p.

Selley, R. C., 1978, Ancient sedimentary environments: Cornell Univ. Press, Ithica, N.Y., 287 p.

Sloss, L. L. and Feray, D. E., 1948, Microstylolites in sandstones: Jour. Sed. Petrology, v. 18, p. 3-13.

Smith, A. D. W., 1895, Report on the anthracite region: in Lesley, J. P., d'Invilliers, E. V., Smith, A. D. W., 1895, A summary description of the geology of Pennsylvania: 2nd Pa. Geol. Survey, Final Rpt., v. 3, pt. 1, p. 1916-2152.

Taylor, J. M., 1950, Pore space reduction in sandstones: Am. Assoc. Petroleum Geologists Bull., V. 34, p. 701-716.

VanHouten, F. B., 1961, Climatic significance of red beds, in Nairn, A.E.M., ed., Descriptive Paleoclimatology: New York, Interscience Publishers, Inc., 380 p.

_______________, 1968, Iron oxides in red beds: Geol. Soc. America Bull., V. 79, p. 399-416.

Waldschmidt, W. A., 1941, Cementing materials in sandstones and their probable influence on migration and accumulation of oil and gas: Am. Assoc. Petroleum Geologists, V. 25, p. 1839-1879.

Walker, R. G., 1975, Conglomerates: Sedimentary structures and facies models, in depositional environments as interpreted from primary sedimentary structures and stratification sequences: Soc. Econ. Paleontologists Mineralogists Short Course No. 2.

Walker, T. R., 1962, Reversible nature of chert-carbonate replacement in sedimentary rocks: Geol. Soc. America Bull., V. 73, p. 237-242.

_______________, 1967, Formation of red beds in modern and ancient deserts: Geol. Soc. America Bull., V. 78, p. 353-368.

White, D., 1900, The stratigraphic succession of the fossil floras of the Pottsville Formation in the southern anthracite coal field, Pennsylvania: U. S. Geol. Survey, Ann. Rpt. 20, pt. 2, p. 749-930.

__________, 1904, Deposition of the Appalachian Pottsville: Geol. Soc. America Bull., V. 15, p. 267-282.

Wolf, K. H. and Chilingarian, G. V., 1976, Diagenesis of sandstones and compaction, in Chilingarian, G. V., and Wolf, K. H., eds., Compaction of coarse-grained sediments II: Developments in Sedimentology, V. 18B, p. 69-444.

Wood, G. H., Jr., Trexler, J. P., and Arndt, H. H., 1962, Pennsylvanian rocks of the southern part of the anthracite region of eastern Pennsylvania: U. S. Geol. Survey, Prof. Paper 450-C, p. 39-42.

________________________________, Arndt, H. H., Yelenosky, A., Soren, J., 1956, Subdivision of Pottsville Formation in southern anthracite field, Pennsylvania: Am. Assoc. Petrol. Geol. Bull., V. 40, p. 2669-2688.

________________________________, and Kehn, T. M., 1969, Geology of the west-central part of the southern anthracite field and adjoining areas, Pennsylvania: U. S. Geol. Survey, Prof. Paper 602, 149 p.

________________________________, Yelenosky, A., Soren, J., 1962, Geology of rocks of Pennsylvanian age in the southern half of the Tremont quadrangle, Schuylkill County, Pennsylvania: U. S. Geol. Survey Bull. 1112, p. 181-208.

Young, S. W., 1976, Petrographic textures of detrital polycrystalline quartz as an aid to interpreting crystalline source rocks: Jour. Sed. Petrology, V. 46, p. 595-603.

APPENDIX I

Datum for the locality of each sample in the measured sections is the Mauch Chunk-transition zone contact.

Sample: JCG-1-78 - Lithic Arkose

Locality: Pottsville section at -37.7 m

Formation: Mauch Chunk

Texture

Grain size: 0.17 mm - fine sand

Sorting: moderately well σ = .48

Grain contacts: point (rare), long, concavo-convex
sutured (rare) mostly concavo-convex

Roundness: framework - subangular
range - angular to rounded (in a few larger grains)

Mineralogy

Framework:

Monocrystalline quartz - 34.7% $\pm$ 1.4%

- mostly equant
- little altered grains showing straight to undulose extinction
- trace amounts of grains with vacuole inclusions

Vein quartz - 2.6% $\pm$ 0.4%

- semicomposite extinction equant individuals

Chert - 5.8% $\pm$ .7%

- some grains have multiple grain size

Quartzite - 8.2% $\pm$ 0.8%

- some grains have elongated individuals and/or sutured contacts

Metamorphic rock fragments - 6.2%$$\pm$ 0.7%

- deformed between framework grains, consists of phyllite and schist (trace)

Sedimentary rock fragments --

Potassium feldspar - 23.7% $\pm$ 1.3%

- altered grains with vacuole inclusions

Plagioclase feldspar (Oligoclase) - 1.0% $\pm$ 0.1%

- altered albite twinned grains
- average twin extinction 10° negative sign $Ab_{88}An_{12}$

Calcite - 3.1% $\pm$ 0.5%

- occurs as sparry or micritic cement and as a few altered grains

Opaques --

Miscellaneous - 4.0% $\pm$ 0.6%

Heavy minerals - Diopside - trace
epidote - trace

Muscovite flakes - trace

Chlorite - .8%

Matrix:

- primarily a pseudomatrix formed by crushed and deformed ductile rock fragments

- minor amount of red stained clay sized material in interstices possibly authigenic

Cement:

- calcite - occurs as poikilotopic sparry twinned pore filling crystals or as small patches of micritic material

- silica - minor amounts of quartz overgrowths are present in optical continuity with host grains

- authigenic clays - present in trace amounts as small red stained aggregate

Sample: JCG-2-78 - Feldspathic Phyllarenite

Locality: Pottsville at -31.2 meters

Formation: Mauch Chunk - Pottsville Transition

Texture

Grain size: 0.2 mm - fine sand

Sorting: moderately well $\sigma = 0.45$

Grain contacts: mostly concavo-convex or irregular - long minor occurrences of sutured and point

Roundness: subangular
lesser amounts of angular grains

Fabric: no preferred orientation

Mineralogy

Framework:

Monocrystalline quartz - 37.8% $\pm$ 1.5%

- most grains are straight to slightly undulatory with little alteration

Vein quartz - 5.9% $\pm$ 0.7%

- some grain show elongated individuals

Chert - 1.3% $\pm$ 0.3%

Quartzite - 7.4% $\pm$ 0.8%

Metamorphic rock fragments - 25.3% $\pm$ 1.3%

- mostly phyllite

Sedimentary rock fragments - 0.2%

- argillaceous material

Potassium feldspar - 14.9% ± 1.1%

- abundant vacuole inclusions
- no twinning

Plagioclase feldspar (albite) - 0.7%

- albite twinned and/or altered grains
- average twin extinction 14° negative optic sign $Ab_{92}An_8$

Calcite - 1.2% ± 0.3%

- mostly as micritic cement and a few altered grains

Opaques - 1.1% ± 0.3%

Miscellaneous - 4.2% ± 0.6%

Heavies - Tourmaline - trace
Diopside - trace

Muscovite - trace

Biotite - trace

Matrix:

- a pseudomatrix formed by crushed and deformed ductile rock fragments

Cement:

- calcite - a few occurrence of micritic patches filling interstices
- silica - rare overgrowths on quartz grains
  - authigenic clay coating some grains

Sample: JCG-4-78 - Phyllarenite

Locality: Pottsville section at -19 meters

Formation: Mauch Chunk

Texture

Grain size: 0.23 mm - fine sand

Sorting: moderately well $\sigma = .49$

Grain contacts: mostly concavo-convex and irregular straight
few sutured and point contacts

Roundness: subangular - some grains are angular or rounded (large grains)

Fabric: numerous elongated quartz and some mica grains oriented parallel to bedding causing a laminated fabric

Mineralogy

Framework:

Monocrystalline quartz - 42.7% $\pm$ 1.5%

- most grains are slight to strongly undulose
- some grains contain numerous vacuoles
- a trace number of grains have inclusions of chlorite

Vein quartz - 11.6% $\pm$ 0.9%

Quartzite - 1.9% $\pm$ 0.4%

Metamorphic rock fragments - 21.7% ± 1.3%

- phyllite and a few pieces of mica schist

Sedimentary rock fragments - 3.7% ± 0.6%

- argillaceous material

K-feldspar - 7.9% ± 0.9%

- untwinned with alterations and numerous vacuole inclusions

Plagioclase feldspar (albite) - 0.3%

- albite twinned and some carlsbad twinned fresh, angular grains

- average 18° twin extinction, negative optic sign $Ab_{95}An_5$

Calcite - 1.0% ± 0.3%

- occurs as cement or a few detrital grains

Opaques - 2.0% ± 0.4%

Miscellaneous - 4.6% ± 0.7%

Heavies - Diopside
Tourmaline
Zircon

Muscovite flakes

- oriented parallel to bedding

Biotite

- elongated flake many altering to hematite

Matrix:

- a pseudomatrix formed by crushed and deformed rock fragments

Cement:

- calcite occurs mostly as micritic or sparry twinned patches

- some authigenic clays occur in pores or as coatings or grains

- most clays are oxidized to hematite

Sample: JCG-5-78 - Feldspathic Phyllarenite

Locality: Pottsville section at 0.2 m.

Formation: Mauch Chunk Pottsville Transition

Texture

Grain size: 0.33 mm - medium sand

Sorting: moderate $\sigma = .58$

Grain contacts: mostly concavo-convex and irregular
many grains are "floating" in a calcite cement

Roundness: subangular to angular - numerous larger grains are subrounded to rounded

Fabric: no preferred orientation

Mineralogy

Framework:

Monocrystalline quartz - 26.5% ± 1.4%

- mostly slightly to highly undulose, however a significant number of grains have straight extinction

- trace amounts of chlorite and rutile are present as inclusions

Vein quartz - 6.1% ± 0.7%

- some grains have subparallel individuals

Chert - 16.0% ± 1.1%

Quartzite - 9.7% ± 0.9%

- most grains have equant individuals

Metamorphic rock fragments - 8.9% ± 0.8%

- phyllites and micaceous schists

Sedimentary rock fragments - 1.6% ± 0.4%

- argillaceous material
- one large (6.5mm) red shale clast is present in the thin section

K-feldspar - 11.3% ± 1.0%

- numerous vacuole inclusions

Plagioclase feldspar --

Calcite - 18.0% ± 1.2%

- occurs as sparry cement or altered grains

Opaques - 1.0% ± 0.3%

Miscellaneous - 1.8% ± 0.4%

Muscovite - trace

Chlorite - trace

Matrix:

- a pseudomatrix formed by crushed and deformed rock fragments

Cement:

- calcite cement occurring as sparry poikilotopic crystals

- trace amount of silica cement occurring as optically continuous overgrowths

Sample: JCG-10-78 - Feldspathic Phyllarenite

Locality: Pottsville section at 1.17 m

Formation: Mauch Chunk - Pottsville Transition

Texture

Grain size: 0.41 mm - medium sand

Sorting: moderately well $\sigma = 0.48$

Grain contacts: mostly irregular and abundant concavo-convex
some sutured

Roundness: subangular and angular grains are abundant

Fabric: slight lamination due to elongated grains that lie subparallel to bedding

Mineralogy

Framework:

Monocrystalline quartz - 35.4% $\pm$ 1.4%

- trace amounts of grains have vermicular chlorite, rutile or vacuole inclusions

Vein quartz - 1.1% $\pm$ 0.3%

- few grains have parallel individuals

Chert - 3.3% $\pm$ 0.5%

Quartzite - 9.9% $\pm$ 0.9%

- some grains have elongated crystals

Metamorphic rock fragments - 18.3% $\pm$ 1.2%

- phyllites and a few schist fragments

Sedimentary rock fragments - 1.0% $\pm$ 0.3%

- argillaceous material

K-feldspar - 22.2% $\pm$ 1.3%

- abundant vacuole inclusions

Plagioclase feldspar --

Calcite - 3.2% $\pm$ 0.6%

- occurs as micritic and sparry cement or as altered detrital grains

Opaques - 2.2% $\pm$ 0.4%

Miscellaneous - 3.4% $\pm$ 0.5%

void spaces - 2.2%

Heavies - 0.4%
Tourmaline
Anatase
Horneblende

Biotite - trace

Muscovite - trace

Matrix:

- pseudomatrix formed by crushed and deformed rock fragments

Cement:

-calcite cement occurring as a few sparry or micritic patches or altered detrital grains

Sample: JCG-11-78 - Subphyllarenite

Locality: Pottsville section at 1.53 meters

Formation: Mauch Chunk - Pottsville Transition

Texture

Grain size: 0.50 mm - medium-coarse sand

Sorting: poor $\sigma = 1.03$
grain size ranges from .03mm - >10mm

Grain contacts: concavo-convex and irregular
minor amounts of sutured and point contacts

Roundness: subangular in fine to medium sand sized fraction
subrounded to well rounded in coarse fraction

Fabric: no preferred orientation

Mineralogy

Framework:

Monocrystalline quartz - 18.4% $\pm$ 1.2%

- most grains are straight or slightly undulatory

- few grains have strain krinkles

- vacuoles, rutile and vermicular chlorite are present as inclusions

Vein quartz - 37.4% ± 1.4%

- the large size fraction is vein quartz

Chert - 2.2% ± 0.4%

Quartzite - 13.5% ± 1.0%

- equant individuals
- some grains show foliation and/or sutured contacts

Metamorphic rock fragments - 6.3% ± 0.7%

- phyllite, micaceous schist

Sedimentary rock fragments - 5.9% ± 0.7%

- argillaceous material

K-feldspar - 3.1% ± 0.5%

- numerous vacuoles

Plagioclase feldspar --

Calcite - 2.3% ± 0.4%

- occurs as minor patches of cement

Opaques - 1.6% ± 0.4%

Miscellaneous - 9.3% ± 0.9%

Heavies - Diopside
Dravite
Zircon

Muscovite

Biotite

Matrix:

- little matrix, but what is present is a pseudomatrix formed by the deformation of ductile rock fragments

Cement:

- minor amounts of calcite cement occurring as sparry twinned crystals

- minor amount of silica cement as quartz overgrowths

Sample: JCG-15-78 - Phyllarenite

Locality: Pottsville section at 15.19 meters

Formation: Mauch Chunk - Pottsville Transition

Texture

Grain size: 0.3 mm - medium sand

Sorting: moderately well $\sigma = 0.41$

Grain contacts: mostly irregular or tangential
few concavo-convex or sutured

Roundness: angular to subangular

Fabric: no preferred orientation

Mineralogy

Framework:

Monocrystalline quartz - 37.5% ± 1.5%

- mostly straight or slightly undulose
- trace amount with rutile undulose

Vein quartz - 11.4% ± 0.8%

Chert - 1.1% ± 0.3%

Quartzite - 1.2% ± 0.3%

- few grains with subparallel grains

Metamorphic rock fragments - 30.6% ± 1.4%

- phyllites, micaceous schists

Sedimentary rock fragments - 0.2%

- argillaceous material

K-feldspar - 4.2% ± 0.6%

- numerous vacuoles

Plagioclase feldspar --

Calcite - 10.5% ± 0.9%

- occurs as sparry cement or some detrital grains

Opaques - 2.4% ± 0.4%

Miscellaneous - 0.9%

Heavies - Pyroxcene
Tourmaline
Diopside

Matrix:

- abundant pseudomatrix formed by crushed and deformed ductile rock fragments

Cement:

- minor amounts of sparry patches of twinned calcite cement

Sample: JCG-16-78 - Feldspathic Phyllarenite

Locality: Pottsville section at 30.54 meters

Formation: Mauch Chunk - Pottsville Transition

Texture

Grain size: 0.35 mm - medium sand

Sorting: moderate $\sigma = 0.69$

Grain contacts: mostly irregular; some point and concavo-convex
numerous grains are floating in a pseudomatrix

Roundness: subangular

Fabric: no preferred orientation

Mineralogy

Framework:

Monocrystalline quartz - 28.8% $\pm$ 1.4%

- mostly slightly undulose
- many grains have vacuole inclusions
- trace amount of vermicular chlorite inclusions

Vein quartz - 1.7% $\pm$ 0.4%

- few grains have subparallel individuals

Chert - 1.7% $\pm$ 0.4%

Quartzite - 9.3% ± 0.9%

Metamorphic rock fragments - 26.8% ± 1.3%

- phyllite, minor amounts of micaceous schist

Sedimentary rock fragments - 0.3%

- argillite

K-feldspar - 13.9% ± 1.0%

- numerous vacuole inclusions

Plagioclase feldspar --

Calcite --

Opaque - 2.2% ± 0.4%

Miscellaneous - 15.3% ± 1.1%

Clay material - 13.3%

Heavies - Diopside

Matrix:

- a pseudomatrix formed by crushed and deformed ductile rock fragments

Cement:

- minor amounts of silica cement

- authigenic clays surrounding some framework grains

Sample: JCG-18-78 - Phyllarenite

Locality: Pottsville section at 41.71 meters

Formation: Mauch Chunk - Pottsville Transition

Texture

Grain size: 0.60 mm - coarse sand

Sorting: moderate $\sigma = 0.70$

Grain contacts: concavo-convex
irregular and point

Roundness: subangular
many of the larger grains are subrounded to rounded

Fabric: no preferred orientation

Mineralogy

Framework:

Monocrystalline quartz - 32.4% $\pm$ 1.4%

- mostly slight to highly undulose
- numerous vacuole inclusions
- trace amount of rutile inclusions

Vein quartz - 11.2% $\pm$ 0.9%

Chert - 11.2% $\pm$ 0.9%

Quartzite - 15.2% $\pm$ 1.0%

- equant sutured crystals

Metamorphic rock fragments - 10.1% $\pm$ 0.9%

- phyllite, micaceous schist, quartz-mica schist

Sedimentary rock fragments - 4.5% $\pm$ 0.7%

- argillaceous material

K-feldspar - 6.9% $\pm$ 0.8%

- some alteration and vacuole inclusions

Plagioclase feldspar --

Calcite - 7.9% $\pm$ 0.8%

- occurs as a cement or detrital grains

Opaques - 0.2%

Miscellaneous - 0.4%

Muscovite flakes - trace

Chlorite - trace

Matrix:

- pseudomatrix formed by crushed and deformed ductile rock fragments

Cement:

- calcite cement occurring as a sparry twinned precipitate

Sample: JCG-21-78 - Phyllarenite

Locality: Pottsville section at 82.45 m

Formation: Mauch Chunk - Pottsville Transition

Texture

Grain size: 1.7 mm - very coarse sand

Sorting: poor $\sigma = 1.48$

Grain contacts: irregular long, point and "floating" grains
some concavo-convex contacts

Roundness: subangular to subrounded
larger grains are rounded

Fabric: no preferred orientation

Mineralogy

Framework:

Monocrystalline quartz - 17.8% ± 1.1%

- mostly straight to highly undulose extinction
- vacuoles, trace of vermicular chlorite inclusions

Vein quartz - 25.6% ± 1.3%

- coarse grained
- most grains have subparallel individuals

Chert - 11.9% ± 0.9%

Quartzite - 18.1% ± 1.1%

- coarse grained

Metamorphic rock fragments - 14.8% ± 1.0%

- phyllites, micaceous schists, quartz mica schists

Sedimentary rock fragments - 6.7% ± 0.8%

- argillite, red shale clasts

K-feldspar - 3.5% ± 0.5%

Plagioclase feldspar --

Calcite --

Opaques - 0.3%

Miscellaneous - 1.3% ± 0.3%

Voids - 0.8%

igneous rock fragment

- altered with altered feldspar laths

unidentified rock fragment comprised of spherical crystals with cross shaped, continuously oriented optical interference figures

some crystals show possible nuclei

Muscovite flakes

Matrix:

- pseudomatrix formed by crushed and deformed ductile rock fragments

Cement:

- minor amounts of silica cement occurring as quartz overgrowths

- clay bonding

Sample: JCG-24-78 - Phyllarenite

Locality: Pottsville section at 106.95 meters

Formation: Mauch Chunk - Pottsville Transition

Texture

Grain size: 0.38 mm - medium sand

Sorting: moderately well $\sigma = 0.43$

Grain contacts: mostly irregular long and concavo-convex

Roundness: subangular

Fabric: slight orientation of elongated grain parallel to bedding

Mineralogy

Framework:

Monocrystalline quartz - 41.5% ± 1.5%

- numerous vacuole inclusions
- mostly undulatory

Vein quartz - 3.7% ± 0.6%

Chert - 3.6% ± 0.6%

Quartzite - 4.3% ± 0.6%

- equant crystals

Metamorphic rock fragments - 34.8% ± 1.3%

- phyllite, some micaceous schist

Sedimentary rock fragments --

K-feldspar - 11.8% $\pm$ 0.8%

- numerous vacuole inclusions

Plagioclase feldspar --

Calcite --

Opaques - 0.2%

Miscellaneous - 0.1%

- Tourmaline
  Diopside

Matrix:

- pseudomatrix formed by crushed and deformed ductile rock fragments

Sample: JCG-26-78 - Feldspathic Phyllarenite

Locality: Pottsville section at 118.34 m

Formation: Mauch Chunk - Pottsville Transition

Texture

Grain size: 1.5 mm - very coarse sand

Sorting: poor $\sigma = 1.63$

Grain contacts: concavo-convex and irregular long

Roundness: subangular - subrounded
some larger grains are well rounded

Fabric: no preferred orientation

Mineralogy

Framework:

Monocrystalline quartz - 21.2% $\pm$ 1.3%

- straight to highly undulose extinction
- strain krinkles
- vermicular chlorite inclusions

Vein quartz - 26.4% $\pm$ 1.3%

- coarse grained and some elongation of individuals

Chert - 7.4% $\pm$ 0.8%

Quartzite - 19.9% $\pm$ 1.2%

- some elongated crystals

Metamorphic rock fragments - 9.0% $\pm$ 0.9%

- phyllite, micaceous schist

Sedimentary rock fragments - 5.5% $\pm$ 0.7%

- argillite, siltstone, fine grained sandstone

K-feldspar - 7.3% $\pm$ 0.8%

Plagioclase feldspar --

Calcite --

Opaque --

Miscellaneous - 3.3% $\pm$ 0.6%

Voids - 2.4%

Chlorite

Matrix:

- pseudomatrix formed from crushed and deformed rock fragments

Cement:

- minor amounts of silica cement occurring as optically continuous quartz overgrowths

Sample: JCG-29-78 - Subphyllarenite

Locality: Pottsville section at 118.34 meters

Formation: Mauch Chunk - Pottsville Transition

Texture

Grain size: 0.40 mm - medium sand

Sorting: moderate $\sigma = 0.54$

Grain contacts: mostly concavo-convex
some irregular and sutured

Roundness: subangular to angular
some larger grains are subrounded

Fabric: no preferred orientation

Mineralogy

Framework:

Monocrystalline quartz - 49.9% ± 1.6%

- mostly straight to slightly undulose
- trace amounts of vermicular chlorite inclusions

Vein quartz - 17.2% ± 1.1%

Chert - 1.1% ± 0.3%

Quartzite - 12.6% ± 1.0%

- equant crystals

Metamorphic rock fragments - 8.6% ± 0.8%

- phyllite, micaceous schists

Sedimentary rock fragments - 2.2% ± 0.4%

K-feldspar - 1.5%

- alteration and vacuoles

Plagioclase feldspar --

Calcite - 2.2% ± 0.4%

- occurs as cement and altered detrital grains

Opaques --

Miscellaneous - 4.7% ± 0.7%

- voids 0.9%
- chlorite - trace

Matrix:

- pseudomatrix formed by crushed and deformed ductile rock fragments

Cement:

- calcite cement occurring as altering pore filling precipitates

Sample: JCG-33-78 - Phyllarenite

Locality: Pottsville section at 161.09 meters

Formation: Mauch Chunk - Pottsville Transition

<u>Texture</u>

Grain size: 0.28 mm - medium sand

Sorting: moderately poor $\sigma = 1.07$

Grain contacts: mostly irregular long and point numerous "floating" grains are present

Roundness: subangular
some larger grains are subrounded

Fabric: laminated due to segregation of size fractions and orientation of elongated grains parallel to bedding

<u>Mineralogy</u>

Framework:

Monocrystalline quartz - 34.4% $\pm$ 1.3%

- mostly slightly undulose

- some grains with vacuoles

Vein quartz - 1.5%

Chert - 5.6% $\pm$ 0.7%

Quartzite - 3.9% $\pm$ 0.6%

- some grains have subparallel individuals

Metamorphic rock fragments - 44.8% ± 1.5%

- phyllite, some micaceous schist

Sedimentary rock fragments --

K-feldspar - 8.4% ± 0.8%

- numerous vacuole inclusions

Plagioclase feldspar --

Calcite --

Opaques - 0.6%

Miscellaneous - 0.8%

Muscovite flakes oriented parallel to bedding-trace

Biotite - trace

Zircon - trace

Matrix:

- abundant pseudomatrix formed by crushed and deformed ductile rock fragments

Cement:

- some cementing is due to clay bonding by the abundant pseudomatrix material

Sample: JCG-35-78 - Phyllarenite

Locality: Pottsville section at 168.65 meters

Formation: Mauch Chunk - Pottsville Transition

<u>Texture</u>

Grain size: 0.30 mm - medium sand

Sorting: moderate $\sigma = 0.82$

Grain contacts: mostly concavo-convex and irregular

Roundness: subangular to subrounded

Fabric: slight orientation of elongated grains parallel to bedding

<u>Mineralogy</u>

Framework:

Monocrystalline quartz - 35.2% $\pm$ 1.4%

- many grains are undulose and/or are strained krinkled

- trace amounts of vermicular chlorite

Vein quartz - 6.2% $\pm$ 0.7%

Chert - 9.0% $\pm$ 0.9%

Quartzite - 7.0% $\pm$ 0.8%

- equant crystals

Metamorphic rock fragments - 28.2% ± 1.3%

- phyllite, micaceous schist

Sedimentary rock fragments - 0.3%

- argillites

K-feldspar - 9.1% ± 0.8%

Plagioclase feldspar --

Calcite - 2.9% ± 0.7%

- occurs as small patches of cement

Opaques - 0.2%

Miscellaneous - 1.9% ± 0.4%

Diopside - trace
Tourmaline - trace
Chlorite - trace

Matrix:

- pseudomatrix formed by crushed and deformed ductile rock fragments

Cement:

- minor amounts of sparry twinned calcite cement

Sample: JCG-39-78 - Feldspathic Phyllarenite

Locality: Pottsville section at 175.86 m

Formation: Mauch Chunk - Pottsville Transition

Texture

Grain size: 0.60 mm - coarse sand

Sorting: moderately poor $\sigma = 0.99$

Grain contacts: concavo-convex, irregular long some point contacts and floating grains are present

Roundness: subangular to subrounded some grains are well rounded

Fabric: no preferred orientation

Mineralogy

Framework:

Monocrystalline quartz - 37.2% ± 1.5%

- straight to highly undulose extinction
- vacuoles, strain krinkles, traces of vermicular chlorite

Vein quartz - 8.1% ± 0.8%

- parallel crystals

Chert - 0.8%

Quartzite - 15.6% ± 1.0%

- some highly sutured contacts

Metamorphic rock fragments - 20.8% $\pm$ 1.2%

- phyllites, micaceous schists

Sedimentary rock fragments - 5.7% $\pm$ 0.8%

- argillites, siltstones, fine grained sandstones

K-feldspar - 11.0% $\pm$ 0.9%

Plagioclase feldspar --

Calcite --

Opaque --

Miscellaneous - 0.8% $\pm$ 0.3%

Void - trace

Matrix:

- pseudomatrix formed by crushed and deformed ductile rock fragments

Cement:

- minor amounts of silica cement occurring as optically continuous overgrowths

- clay bonding

Sample: JCG-40-78 - Subphyllarenite

Locality: Pottsville section at 82.30 meters

Formation: Mauch Chunk - Pottsville Transition

Texture

Grain size: 0.34 mm - medium sand

Sorting: poor $\sigma = 1.12$

Grain contacts: irregular concavo-convex
significant amounts of floating grains are present

Roundness: subangular to subrounded
some larger grains are rounded

Fabric: no preferred orientation

Mineralogy

Framework:

Monocrystalline quartz - 25.3% $\pm$ 1.3%

- mostly straight extinction, some grains are slightly undulose

- several grains have vermicular chlorite inclusions and a trace amount have rutile inclusions

Vein quartz - 43.8% $\pm$ 1.5%

- most of the larger grain size fraction is vein quartz

- coarse unoriented crystals

Chert - 2.3% $\pm$ 0.4%

Quartzite - 10.6% $\pm$ 0.9%

- equant sutured individuals

Metamorphic rock fragments - 8.7% $\pm$ 0.8%

- phyllite and quartz mica schist

Sedimentary rock fragments - 2.5% $\pm$ 0.4%

- argillaceous material and silt and fine grained sandstone

K-feldspar - 1.6% $\pm$ 0.4%

Plagioclase feldspar --

Calcite --

Opaques --

Miscellaneous - 5.2% $\pm$ 0.7%

Biotite flakes - trace

Zircon - trace

Matrix:

- pseudomatrix formed from crushed and deformed ductile rock fragments

Cement:

- some authigenic clays are present surrounding some framework grains

Sample: JCG-45-79 - Phyllarenite

Locality: Pottsville section at 195.51 m

Formation: Mauch Chunk - Pottsville Transition

Texture

Grain size: 0.41 mm - medium sand

Sorting: moderately well $\sigma = 0.44$

Grain contacts: concavo-convex, irregular long some point contacts and floating grains

Roundness: subangular to subrounded

Fabric: no preferred orientation

Mineralogy

Framework:

Monocrystalline quartz - 41.6% ± 1.5%

- straight to highly undulose extinction
- vacuoles, strain krinkles, and a trace of vermicular chlorite inclusions

Vein quartz - 3.5% ± 0.6%

- some grains have subparallel individuals

Chert - 1.8% ± 0.4%

Quartzite - 5.3% ± 0.7%

- fine grained

Metamorphic rock fragments - 35.7% ± 1.4%

- phyllites, micaceous schists

Sedimentary rock fragments - 0.3%

- argillites

K-feldspar - 11.7% ± 0.9%

Plagioclase feldspar --

Calcite --

Opaque --

Miscellaneous - 0.1%

Matrix:

- pseudomatrix formed by crushed and deformed ductile rock fragments

Cement:

- minor amounts of silica cement occurring as optically continuous overgrowths

- abundant clay bonding

Sample: JCG-47-78 - Phyllarenite

Locality: Pottsville section at 203.96 meters

Formation: Mauch Chunk - Pottsville Transition

Texture

Grain size: 0.38 mm - medium sand

Sorting: moderately well $\sigma = 0.44$

Grain contacts: irregular long, concavo-convex, point

Roundness: angular - subangular
few grains are rounded to subrounded

Fabric: very slight orientation of elongated grains parallel to bedding

Mineralogy

Framework:

Monocrystalline quartz - 31.8% $\pm$ 1.4%

- mostly straight to slightly undulose

Vein quartz - 3.5% $\pm$ 0.5%

- few grains have subparallel individuals

Chert - 2.1% $\pm$ 0.4%

Quartzite - 4.2% $\pm$ 0.6%

Metamorphic rock fragments - 34.4% $\pm$ 1.4%

- phyllite and quartz mica schist

Sedimentary rock fragments - 1.2%

- argillites

K-feldspar - 10.0% ± 0.9%

Plagioclase feldspar --

Calcite --

Opaques - 1.6% ± 0.4%

Miscellaneous - 1.8% ± 0.4%

Biotite flakes - trace

Muscovite flakes - trace

Zircon - trace

Chlorite - trace

Matrix:

- mostly a pseudomatrix formed by crushed and deformed ductile rock fragments
- some clay sized material present in interstices 9.4% ± 0.9%

Sample: JCG-48-78 - Phyllarenite

Locality: Pottsville section at 208.29 meters

Formation: Mauch Chunk - Pottsville Transition

Texture

Grain size: 0.39 mm - medium sand

Sorting: moderately well $\sigma = 0.48$

Grain contacts: irregular long, some point and concavo-convex

Roundness: angular - subangular
few grains are subrounded

Fabric: very slight orientation of elongated grains parallel to bedding

Mineralogy

Framework:

Monocrystalline quartz - 42.0% ± 1.5%

- mostly straight to slightly undulose
- few grains with vermicular chlorite inclusions

Vein quartz - 14.3% ± 1.0%

- fine grained

Chert - 3.1% ± 0.6%

Quartzite - 3.9% ± 0.6%

Metamorphic rock fragments - 18.6% $\pm$ 1.1%

- phyllite, micaceous schists

Sedimentary rock fragments - 5.1% $\pm$ 0.7%

- argillaceous material

K-feldspar - 6.2% $\pm$ 0.8%

Plagioclase feldspar --

Calcite --

Opaques - 0.5%

Miscellaneous - 2.2% $\pm$ 0.4%

Muscovite flakes - 0.1%

Voids - 1.5%

Biotite - trace

Matrix:

- pseudomatrix formed by crushed and deformed ductile rock fragments
- clay material (4.1%) is present in interstices

Sample: JCG-51-78 - Phyllarenite

Locality: Pottsville section at 219.43 meters

Formation: Pottsville

Texture

Grain size: 0.75 mm - coarse sand

Sorting: poor $\sigma = 1.31$

Grain contacts: mostly irregular long and point some concavo-convex and "floating"

Roundness: subangular - subrounded (especially in larger size fraction)

Fabric: no preferred orientation

Mineralogy

Framework:

Monocrystalline quartz - 31.5% $\pm$ 1.4%

- mostly undulatory extinction
- trace amounts of vermicular chlorite or rutile inclusions
- numerous vacuoles

Vein quartz - 8.6% $\pm$ 0.8%

- restricted to larger size fractions
- many grains have subparallel individuals

Chert - 0.5%

Quartzite - 10.0% $\pm$ 0.8%

- few grains show some elongation

Metamorphic rock fragments - 28.5% $\pm$ 1.3%

- phyllite, quartz mica schist

Sedimentary rock fragments - 6.7% $\pm$ 0.8%

- argillite, siltstone and fine grained sandstone

K-feldspar - 12.3% $\pm$ 1.0%

Plagioclase feldspar --

Calcite --

Opaques --

Miscellaneous - 1.9% $\pm$ 0.4%

Biotite flakes - trace
large flakes squeezed between grains

Muscovite flakes - trace

Matrix:

- abundant pseudomatrix formed by crushed and deformed rock fragments

Sample: JCG-52-78 - Sedarenite

Locality: Pottsville section at 230.40 m

Formation: Pottsville

Texture

Grain size: 2.68 mm - granule

Sorting: poor $\sigma = 1.77$

Grain contacts: concavo-convex, irregular long numerous point contacts and "floating" grains are present

Roundness: subrounded
larger fraction is rounded to well rounded

Fabric: no preferred orientation

Mineralogy

Framework:

Monocrystalline quartz - 10.3% $\pm$ 0.9%

- straight to highly undulose extinction
- strain krinkles
- chlorite inclusions

Vein quartz - 47.4% $\pm$ 1.6%

- very coarse grained and/or numerous parallel crystals
- comprises most of large size fraction

Chert - 0.7%

Quartzite - 14.9% ± 1.1%

- some elongated individuals and numerous sutured contacts

Metamorphic rock fragments - 0.2%

- phyllite

Sedimentary rock fragments - 24.2% ± 1.3%

- argillites, siltstones, fine grained sandstones

K-feldspar - 1.2% ± 0.3%

Plagioclase feldspar --

Calcite --

Opaque - 0.1%

Miscellaneous - 1.0% ± 0.3%

Chlorite - 0.3%

Voids - 0.5%

Matrix:

- abundant pseudomatrix formed by crushed and deformed ductile rock fragments

Cement:

- minor amount of optically continuous quartz overgrowths

- clay bonding

Sample: JCG-58-78 - Feldspathic phyllarenite

Locality: Jim Thorpe section at -13.76 meters

Formation: Mauch Chunk

Texture

Grain size: 0.18 mm - fine sand

Sorting: moderately well $\sigma = 0.40$

Grain contacts: mostly irregular and some concavo-convex

Roundness: subangular
some grains are angular or subrounded

Fabric: laminated due to high degree of orientation of elongated grains parallel to bedding

Mineralogy

Framework:

Monocrystalline quartz - 27.0% $\pm$ 1.3%

- straight to slightly undulose
- some vacuoles

Vein quartz - 1.0%

Chert - 1.3%

Quartzite - 3.3% $\pm$ 0.6%

Metamorphic rock fragments - 32.9% $\pm$ 1.4%

- phyllites, micaceous schist

Sedimentary rock fragments - 0.1%

- argillite

K-feldspar - 23.8% ± 1.2%

- abundant vacuole inclusions

Plagioclase feldspar (Oligoclase) - 0.7%

- fresh albite twinned grains

- 10° average extinction, negative sign $Ab_{90}An_{10}$

Calcite - 1.2% ± 0.3%

- occurs as cement and detrital grains

Opaques - 4.7% ± 0.7%

- hematite

Miscellaneous - 4.0% ± 0.6%

Muscovite flakes - 1.6%

- oriented parallel to bedding

Biotite flakes - 0.4%

- oriented parallel to bedding

- some alteration to hematite

Tourmaline - trace

Diopside - trace

Matrix:

- pseudomatrix formed by crushed and deformed rock fragments

- much of the matrix material is stained red by oxidation

Cement:

- calcite cement occurring as micritic patches
- minor amounts of silica cementation

Sample: JCG-59-78 - Feldspathic Phyllarenite

Locality: Jim Thorpe section at -6.98 meters

Formation: Mauch Chunk

Texture

Grain size: 0.14 mm - fine sand

Sorting: moderately well $\sigma = 0.38$

Grain contacts: concavo-convex and irregular
long
some point contacts are present

Roundness: angular to subangular

Fabric: laminated due to high degree of orientation of elongated grains parallel to bedding

Mineralogy

Framework:

Monocrystalline quartz - 36.7% $\pm$ 1.4%

- mostly slightly to highly undulose
- few grains have vermicular chlorite inclusions

Vein quartz - 12.0% $\pm$ 1.0%

- very fine grained

Chert - 1.1%

Quartzite - 1.8% $\pm$ 0.4%

- very fine grained

Metamorphic rock fragments - 18.5% $\pm$ 1.1%

- phyllites, few schistose grains

Sedimentary rock fragments - 3.5% $\pm$ 0.8%

- argillaceous material

K-feldspar - 13.5% $\pm$ 1.0%

- shows alteration

Plagioclase feldspar (albite) - 1.2% $\pm$ 0.3%

- fresh albite twinned grains
- average 12° extinction of twins, negative sign

Calcite - 2.2% $\pm$ 0.4%

- occurs as a micritic cement

Opaques - 5.4% $\pm$ 0.7%

- hematite

Miscellaneous - 4.1% $\pm$ 0.6%

Biotite flakes - 0.1%

- oriented parallel to bedding
- some is altering to hematite

Muscovite flakes - 0.5%

- oriented parallel to bedding

Diopside - trace

Tourmaline - trace

Matrix:

- pseudomatrix formed by crushed and deformed ductile rock fragments

- abundant matrix material is being oxidized to red hematite

Cement:

- minor amounts of micritic calcite patches

Sample: JCG-61-78 - Lithic Arkose

Locality: Jim Thorpe section at 2.5 meters

Formation: Mauch Chunk - Pottsville Transition

Texture

Grain size: 0.58 mm - coarse sand

Sorting: moderate $\sigma = 0.79$

Grain contacts: concavo-convex, irregular long
few sutured contacts

Roundness: subangular
few grains are subrounded

Fabric: no preferred orientation

Mineralogy

Framework:

Monocrystalline quartz - 39.0% ± 1.5%

- undulose extinction

- vacuole inclusions

Vein quartz - 1.4% ± 0.3%

Chert - 0.8%

Quartzite - 9.6% ± 0.9%

- coarse equant crystals

Metamorphic rock fragments - 21.6% ± 1.3%

- phyllite, micaceous schist

Sedimentary rock fragments - 0.2%

- argillite

K-feldspar - 24.8% ± 1.3%

- numerous grains are altered

- vacuole inclusions

Plagioclase feldspar (Oligoclase) - 0.3%

- fresh albite twinned grains

- average 8° twin extinction, negative optic sign $Ab_{84}An_{16}$

Calcite - 1.0% ± 0.3%

- occurs as minor patches of micritic cement

Opaques - 0.5%

Miscellaneous - 0.8% ± 0.3%

Muscovite flakes - 0.3%

Biotite - 0.2%

Matrix:

- pseudomatrix formed from crushed and deformed rock fragments

Cement:

- minor amounts of calcite cement occurring as micritic pore filling patches

Sample: JCG-62-78 - Subsedarenite

Locality: Jim Thorpe section at 6.93 meters

Formation: Mauch Chunk - Pottsville Transition

Texture

Grain size: 1.8 mm - very coarse sand

Sorting: poor $\sigma = 1.81$

Grain contacts: concavo-convex, irregular long
few sutured contacts

Roundness: subangular
large grains are subrounded to rounded

Fabric: slight orientation of elongated grains
parallel to bedding

Mineralogy

Framework:

Monocrystalline quartz - 12.2% ± 1.0%

- vacuole inclusions
- strain krinkles
- few vermicular chlorite inclusions

Vein quartz - 22.8% ± 1.3%

- coarse subparallel crystals

Chert - 1.0% ± 0.3%

Quartzite - 50.6% ± 1.6%

- comprises most of largest grain size fraction

- equant and elongated crystals

Metamorphic rock fragments - 4.0% ± 0.6%

- phyllites, schists

Sedimentary rock fragments - 4.5% ± 0.6%

- argillite, siltstone and fine grained sandstone

K-feldspar - 1.1% ± 0.3%

Plagioclase feldspar (albite) - 1.6% ± 0.4%

- fresh and altered albite twinned grains

- average 12° twin extinction, negative optic sign $Ab_{92}An_8$

Calcite --

Opaque - 0.5%

Miscellaneous - 1.7% ± 0.4%

Muscovite flakes

- slight orientation parallel to bedding

Garnet - trace

Diopside - trace

Tourmaline - trace

Matrix:

- pseudomatrix formed by crushed and deformed ductile rock fragments

Sample: JCG-63-78 - Lithic Arkose

Locality: Jim Thorpe section at 163.31 meters

Formation: Pottsville

Texture

Grain size: 0.80 mm - coarse sand

Sorting: moderately well σ = 0.41

Grain contacts: irregular long, concavo-convex few sutured and "floating" grains

Roundness: subangular
larger grains are subrounded to rounded

Fabric: no preferred orientation

Mineralogy

Framework:

Monocrystalline quartz - 39.6% ± 1.5%

- vacuoles
- strain krinkles
- straight to slight and highly undulose

Vein quartz - 17.6% ± 1.1%

- subparallel crystals

Chert - 1.6% ± 0.4%

Quartzite - 9.2% ± 0.9%

- equant crystals; few grains are foliated

Metamorphic rock fragments - 4.5% $\pm$ 0.6%

- phyllite, micaceous schists

Sedimentary rock fragments - 4.4% $\pm$ 0.6%

- argillite, siltstone and fine grained sandstone

K-feldspar - 23.0% $\pm$ 1.2%

- vacuoles

- some alteration

Plagioclase feldspar --

Calcite --

Opaques --

Miscellaneous - 0.1%

Muscovite flakes - 0.1%

Matrix:

- pseudomatrix formed by crushed and deformed rock fragments

Cement:

- very minor amounts of silica cement occurring as quartz overgrowths

Sample: JCG-66-78 - Subphyllarenite

Locality: Wyoming - Lackawanna section at 128.19 m

Formation: Mauch Chunk - Pottsville Transition

Texture

Grain size: 0.20 mm - fine sand

Sorting: moderately well $\sigma = 0.48$

Grain contacts: concavo-convex, irregular long some sutured

Roundness: angular to subangular some large grains are subrounded to rounded

Fabric: laminated due to segregation of grain size fractions and orientation of elongated grains parallel to bedding

Mineralogy

Framework:

Monocrystalline quartz - 60.7% ± 1.5%

- few grains with vacuoles and/or vermicular chlorite inclusions
- straight to slightly undulose

Vein quartz - 9.8% ± 0.9%

- fine grained

Chert - 3.1% ± 0.5%

Quartzite - 3.3% $\pm$ 0.5%

- fine equant grains
- some grains show good foliation

Metamorphic rock fragments - 8.8% $\pm$ 0.8%

- phyllite, schists

Sedimentary rock fragments - 1.3% $\pm$ 0.3%

- argillites

K-feldspar - 7.8% $\pm$ 0.8%

- some alteration and numerous vacuole inclusions

Plagioclase feldspar (Oligoclase) - 0.4%

- fresh albite twinned grains
- some calcite replacement
- average twin extinction - 8° negative sign $Ab_{86}An_{14}$

Calcite - 3.1% $\pm$ 0.5%

- occurs as altered detrital grains and little cement

Opaques - 0.4%

Miscellaneous - 2.0% $\pm$ 0.4%

Muscovite flakes - 0.4%

- oriented parallel to bedding

voids - 0.6%

Matrix:

- small amounts of pseudomatrix formed by crushed and deformed ductile rock fragments

Cement:

- minor amounts of micritic calcite cement

Sample: JCG-67-78 - Lithic Arkose

Locality: Wyoming - Lackawanna section at 122.84 m

Formation: Mauch Chunk - Pottsville Transition

Texture

Grain size: 0.34 mm - medium sand

Sorting: moderate $\sigma = 0.66$

Grain contacts: concavo-convex, irregular long, numerous contacts

Roundness: subangular
larger grains are generally subrounded

Fabric: no preferred orientation

Mineralogy

Framework:

Monocrystalline quartz - 42.3% $\pm$ 1.4%

- vacuoles
- mostly undulose extinction

Vein quartz - 2.7% $\pm$ 0.5%

- numerous subparallel crystals

Chert - 0.9% $\pm$ 0.3%

Quartzite - 4.3% $\pm$ 0.6%

- some elongated crystals

Metamorphic rock fragments - 6.7% $\pm$ 0.8%

- phyllite, micaceous schist

Sedimentary rock fragments - 1.5% $\pm$ 0.3%

- argillite

K-feldspar - 21.4% $\pm$ 1.2%

- numerous vacuoles and alterations

Plagioclase feldspar --

Calcite - 18.5% $\pm$ 1.1%

- occurs as detrital grains or poikilotopic cement

Opaques - 0.3%

Miscellaneous - 1.4% $\pm$ 0.3%

Voids - 0.7%

Muscovite flakes - 0.1%

Hornblende - 0.1%

Zircon - trace

Matrix:

- some pseudomatrix formed by crushed and deformed rock fragments

Cement:

- calcite occurs as poikilotopic, sparry twinned crystals or micritic patches

- abundant silica cement occurring as optically continuous quartz overgrowths - most host grain outlines are indistinguishable

Sample: JCG-68-78 - Phyllarenite

Locality: Wyoming - Lackawanna section at 123.44m

Formation: Mauch Chunk - Pottsville Transition

Texture

Grain size: 0.31 mm - medium sand

Sorting: moderate $\sigma = 0.89$

Grain contacts: irregular long, concavo-convex some "floating" grains in calcite cement

Roundness: angular to subangular

Fabric: no preferred orientation

Mineralogy

Framework:

Monocrystalline quartz - 32.4% ± 1.4%

- mostly straight and slightly undulose extinction
- trace amount of vermicular chlorite inclusions

Vein quartz - 18.2% ± 1.2%

Chert - 0.3%

Quartzite - 4.3% ± 0.4%

- some elongated grains

Metamorphic rock fragments - 13.6% $\pm$ 1.0%

- phyllite, micaceous schists

Sedimentary rock fragments - 2.6% $\pm$ 0.5%

- argillites

K-feldspar - 3.4% $\pm$ 0.5%

- alterations and vacuoles

Plagioclase feldspar --

Calcite - 24.5% $\pm$ 1.3%

- occurs as altered detrital grains and poikilotopic cement

Opaques - 0.2%

Miscellaneous - 0.5%

Muscovite flakes - 0.1%

Biotite flakes - 0.1%

Voids - 0.2%

Matrix:

- pseudomatrix formed by crushed and deformed rock fragments

Cement:

- abundant poikilotopic sparry twinned calcite cement

Sample: JCG-69-79 - Feldspathic Sedarenite

Locality: McAdoo section at -2.48 m

Formation: Mauch Chunk - Pottsville Transition

<u>Texture</u>

Grain size: 1.1 mm - very coarse sand

Sorting: moderate $\sigma = 0.81$

Grain contacts: concavo-convex, irregular long, some point contacts and "floating" grains

Roundness: subangular - subrounded

Fabric: no preferred orientation

<u>Mineralogy</u>

Framework:

Monocrystalline quartz - 31.5% $\pm$ 1.4%

- mostly straight to slightly and highly undulose extinction
- vacuoles and traces of vermicular chlorite
- strain krinkles

Vein quartz - 2.6% $\pm$ 0.5%

- some grains show parallel individuals

Chert - 2.5% $\pm$ 0.5%

Quartzite - 12.7% ± 1.0%

- some elongated crystals

Metamorphic rock fragments - 13.9% ± 1.0%

- phyllites, mica schists, quartz mica schists

Sedimentary rock fragments - 22.6% ± 1.3%

- argillites, siltstones and sandstones

K-feldspar - 12.7% ± 1.0%

Plagioclase feldspar --

Calcite --

Opaques -- 0.1%

Miscellaneous - 1.4% ± 0.3%

Void - 1.0%

Muscovite flakes - 0.1%

Matrix:

- abundant pseudomatrix formed by crushed and deformed rock fragments

Cement:

- abundant clay bonding

Sample: JCG-72-79 - Phyllarenite

Locality: McAdoo section at 13.80 m

Formation: Mauch Chunk - Pottsville Transition

Texture

Grain size: 0.52 mm - coarse sand

Sorting: moderate $\sigma = 0.69$

Grain contacts: concavo-convex, irregular long
some point contacts are present

Roundness: angular to subangular

Fabric: very slight orientation of elongated grains parallel to bedding

Mineralogy

Framework:

Monocrystalline quartz - 43.7% ± 1.5%

- straight to slightly undulose
- some vacuole inclusions and trace amounts of vermicular chlorite and rutile inclusions
- strain krinkles

Vein quartz - 20.7% ± 1.3%

- some grains have subparallel individuals

Chert - 0.3%

Quartzite - 1.3% ± 0.3%

- fine grained

Metamorphic rock fragments - 22.0% ± 1.3%

- phyllite, micaceous schist

Sedimentary rock fragments - 5.3% ± 0.7%

- argillite, siltstone and fine grained sandstone

K-feldspar - 6.1% ± 0.7%

- abundant vacuoles

Plagioclase feldspar --

Calcite - 0.2% ±

- occurs as detrital grains

Opaques - 0.1%

Miscellaneous - 0.3%

Chlorite

Matrix:

- pseudomatrix formed by crushed and deformed rock fragments

Sample: JCG-75-79 - Lithic Arkose

Locality: McAdoo section at 36.58 m

Formation: Pottsville

Texture

Grain size: 0.38 mm - medium sand

Sorting: moderately poor $\sigma = 0.91$

Grain contacts: concavo-convex, sutured
some irregular, long
few microstyolites

Roundness: angular to subangular
some larger grains are subrounded

Fabric: no preferred orientation

Mineralogy

Framework:

Monocrystalline quartz - 37.6% $\pm$ 1.4%

- mostly slight to highly undulose
- vacuoles, strain krinkles
- trace of vermicular chlorite inclusions

Vein quartz - 3.1% $\pm$ 0.6%

- many grains have subparallel individuals

Chert - 4.0% $\pm$ 0.6%

Quartzite - 9.2% ± 0.9%

- some grains show elongated individuals

Metamorphic rock fragments - 18.0% ± 1.1%

- phyllite, micaceous schist

Sedimentary rock fragments - 2.1% ± 0.4%

- argillites

K-feldspar - 24.4% ± 1.3%

- altered grains with vacuole inclusions

Plagioclase feldspar --

Calcite --

Opaques - 0.6%

Miscellaneous - 1.0% ± 0.3%

Muscovite flakes

Voids

Matrix:

- pseudomatrix formed by crushed and deformed rock fragments

Cement:

- minor amounts of silica cement occurring as quartz overgrowths

Sample: JCG-76-79 - Phyllarenite

Locality: McAdoo section at 37.77 m

Formation: Pottsville

Texture

Grain size: 0.38 mm - medium sand

Sorting: moderate $\sigma = 0.76$

Grain contacts: concavo-convex, irregular long, few point contacts and floating grains

Roundness: angular - subangular
some larger grains are subrounded to rounded

Fabric: very slight orientation of elongated grains parallel to bedding

Mineralogy

Framework:

Monocrystalline quartz - 45.4% $\pm$ 1.5%

- slight to highly undulose
- vacuoles
- trace amounts of chlorite inclusions

Vein quartz - 16.6% $\pm$ 1.1%

- many grains have subparallel crystals

Chert - 1.2% $\pm$ 0.3%

Quartzite - 2.8% ± 0.6%

Metamorphic rock fragments - 14.7% ± 1.0%

- phyllites, micaceous schists

Sedimentary rock fragments - 10.0% ± 0.9%

- argillites

K-feldspar - 7.5% ± 0.8%

Plagioclase feldspar --

Calcite --

Opaques - 0.1%

Miscellaneous - 1.7% ± 0.4%

Muscovite flakes - 0.3%

Biotite - 0.2%

Voids - 0.2%

Matrix:

- pseudomatrix formed by crushed and deformed rock fragments

Sample: JCG-80-79 - Subsedarenite

Locality: Wyoming - Lackawanna section at 76.31 m

Formation: Mauch Chunk - Pottsville Transition

Texture

Grain size: 0.26 mm - medium sand

Sorting: moderately well $\sigma = 0.40$

Grain contacts: concavo-convex and sutured contacts
some irregular long contacts are present

Roundness: subangular - subrounded

Fabric: no preferred orientation

Mineralogy

Framework:

Monocrystalline quartz - 76.0% ± 1.3%

- slight to highly undulose extinction
- strain krinkle and vacuoles

Vein quartz - 3.2% ± 0.6%

- elongated and subparallel individuals

Chert - 0.4%

Quartzite - 1.2% ± 0.3%

- fine grained

Metamorphic rock fragments - 4.8% $\pm$ 0.7%

- phyllite, micaceous schist

Sedimentary rock fragments - 5.6% $\pm$ 0.7%

- argillite

K-feldspar - 7.6% $\pm$ 0.8%

Plagioclase feldspar --

Calcite --

Opaques - 0.4%

Miscellaneous - 0.8%

Muscovite flakes

Matrix:

- pseudomatrix formed by crushed and deformed ductile rock fragments

Sample: JCG-81-79 - Subsedarenite

Locality: Wyoming - Lackawanna section at 36.18 m

Formation: Mauch Chunk - Pottsville Transition

Texture

Grain size: 0.29 mm - medium sand

Sorting: moderately poor $\sigma = 0.87$

Grain contacts: concavo-convex, irregular long, minor amounts of sutured contacts

Roundness: subangular - subrounded

Fabric: very slight orientation of elongated grains parallel to bedding

Mineralogy

Framework:

Monocrystalline quartz - 68.0% $\pm$ 1.4%

- straight to slightly undulose extinction
- vacuoles

Vein quartz - 12.1% $\pm$ 0.9%

- many grains have subparallel individuals

Chert - 1.3% $\pm$ 0.3%

Quartzite - 2.8% $\pm$ 0.5%

- mostly fine grained and/or elongated crystals

Metamorphic rock fragments - 3.6% ± 0.6%

- phyllites, schists

Sedimentary rock fragments - 4.6% ± 0.7%

- argillites, siltstones

K-feldspar - 4.3% ± 0.6%

- numerous vacuole inclusions

Plagioclase feldspar --

Calcite --

Opaques - 0.1%

Miscellaneous - 3.2% ± 0.5%

Biotite

Muscovite

authigenic clay

Tourmaline

Matrix:

- pseudomatrix formed by crushed and deformed rock fragments

- authigenic clay coating some grains

Sample: JCG-82-79 - Phyllarenite

Locality: Wyoming - Lackawanna section at -5.11 m

Formation: Mauch Chunk

Texture

Grain size: 0.19 mm - fine sand

Sorting: moderately well $\sigma = 0.52$

Grain contacts: irregular long, long, lesser amounts of concavo-convex and "floating" grains

Roundness: angular to subangular

Fabric: slightly laminated due to orientation of elongated grains parallel to bedding

Mineralogy

Framework:

Monocrystalline quartz - 38.8% $\pm$ 1.5%

- straight to highly undulose extinction
- vacuoles

Vein quartz - 6.0% $\pm$ 0.7%

- fine grained

Chert - 0.8%

Quartzite - 3.2% $\pm$ 0.5%

- some grains have elongated crystals

Metamorphic rock fragments - 36.% ± 1.5%

- phyllites

Sedimentary rock fragments - 3.6% ± 0.5%

- argillites

K-feldspar - 5.2% ± 0.4%

Plagioclase feldspar - trace

- albite twinned grains, some alterations

Calcite - 4.0% ± 0.6%

- occurs as small micritic patches of cement

Opaques - 1.2% ± 0.3%

Miscellaneous - 1.2% ± 0.3%

Muscovite

Biotite

Matrix:

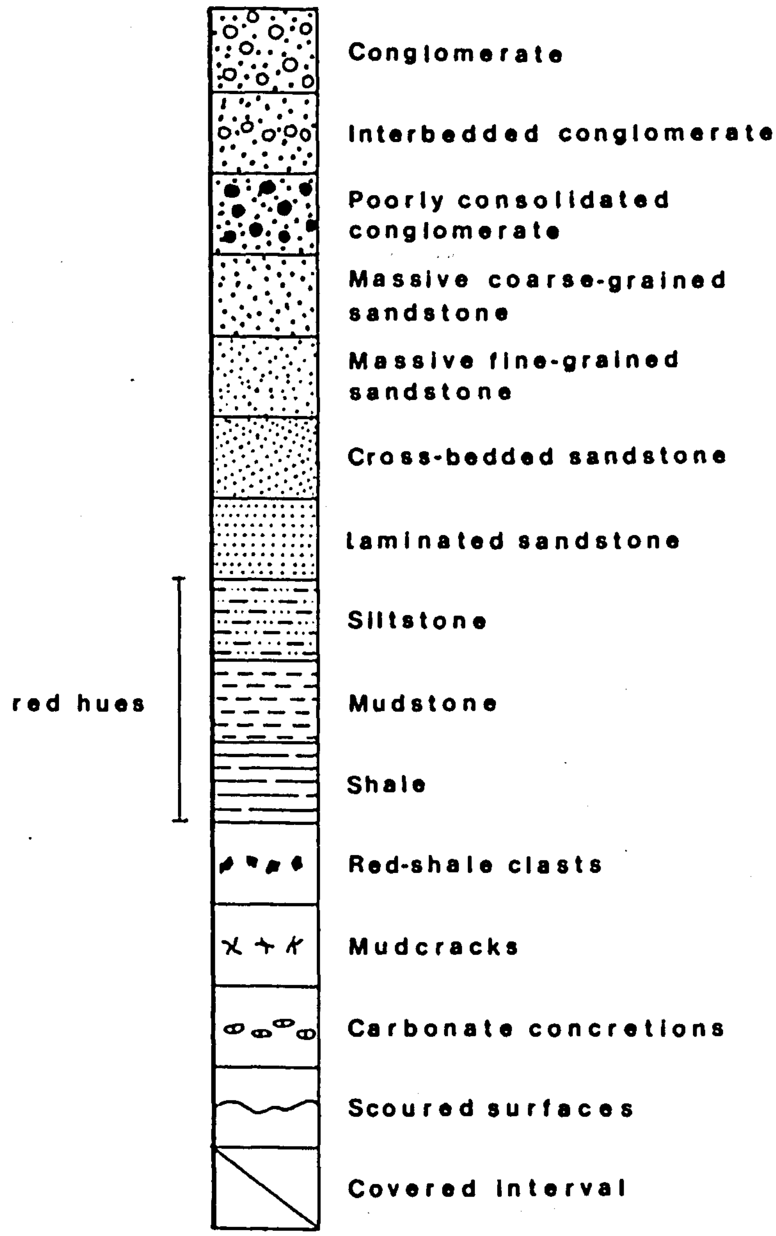
- pseudomatrix formed by crushed and deformed rock fragments

Cement:

- minor amounts of micritic patches calcite cement

APPENDIX II

KEY FOR MEASURED SECTIONS

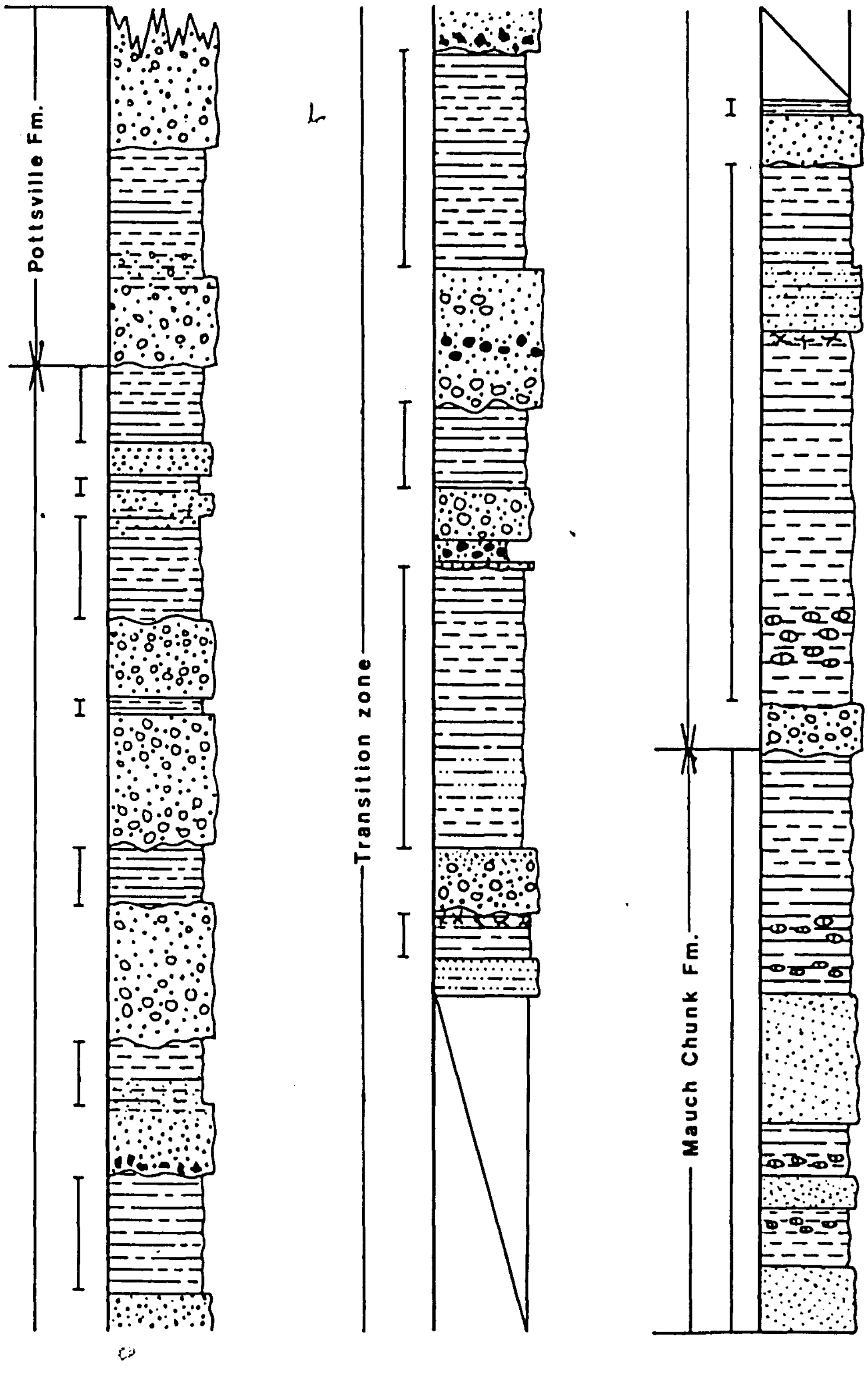


Scale :1 cm. equals 5 meters

SECTION 1 - POTTSVILLE SECTION

The transition zone is completely exposed, including the entire Pottsville Formation and part of the Mauch Chunk Formation in a road cut 1.6 kilometers south of Pottsville through Sharp Mountain in the northbound lane along Route 61. The beds have an average strike of N66°E and dip to the south at an average angle of 77°.

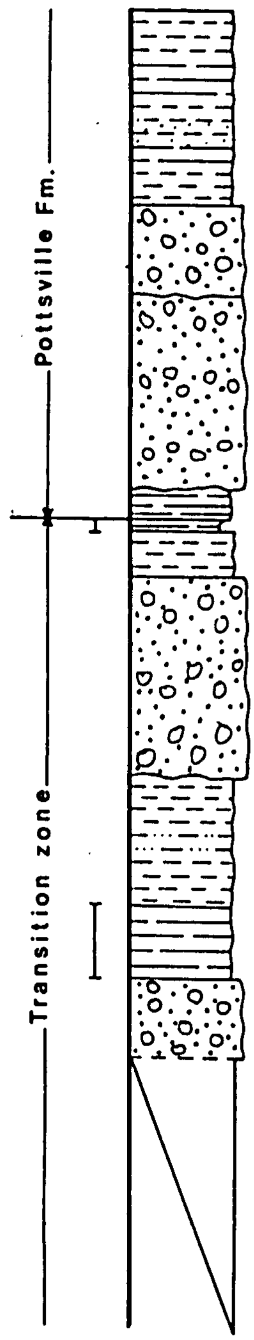
POTTSVILLE



SECTION 2 - McADOO SECTION

The McAdoo Section is exposed in a road cut at the McAdoo exit along Route I-81 north. The beds have an average strike and dip of N59°E and 23°S respectively.

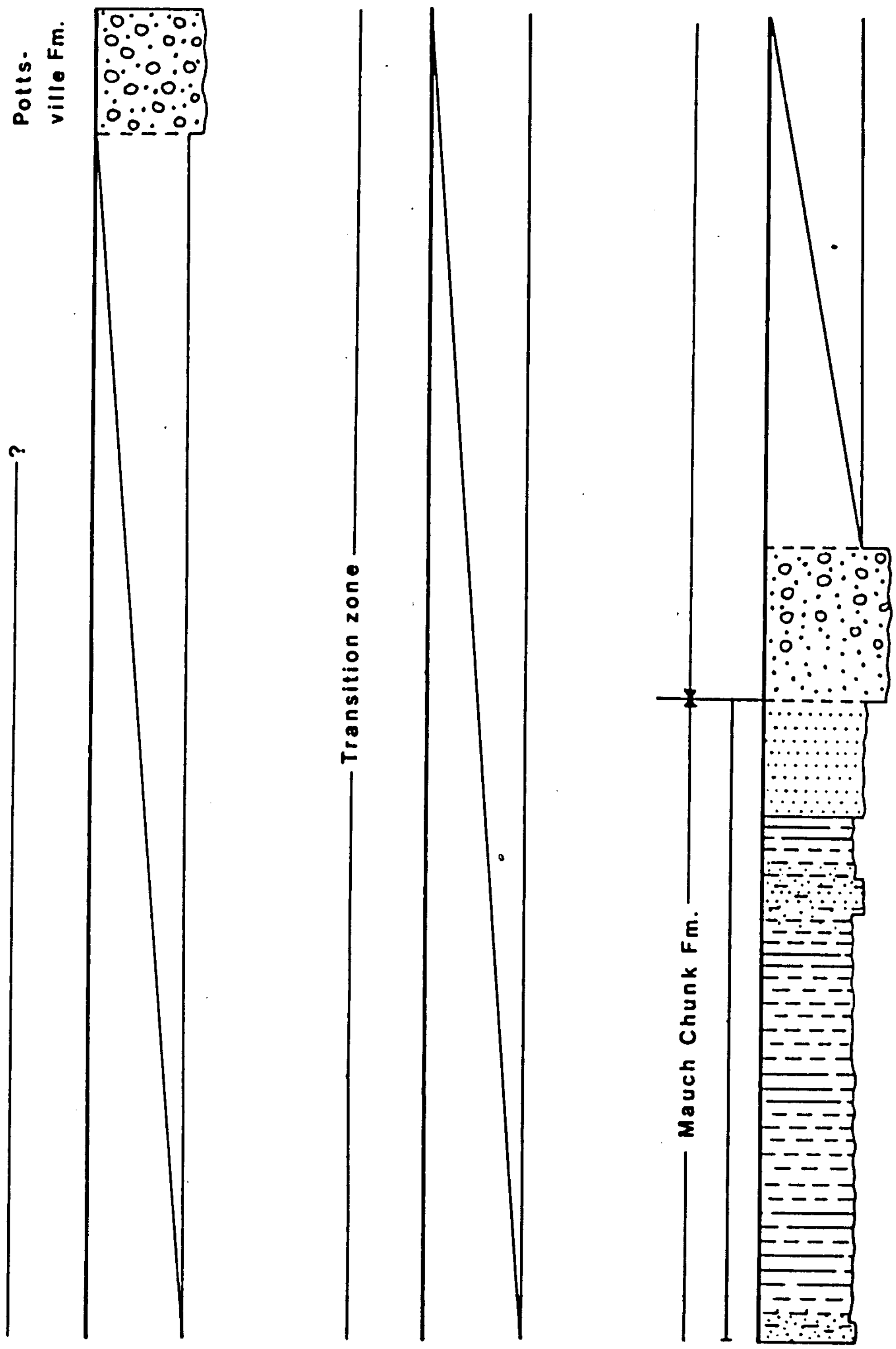
McADOO



SECTION 3 - JIM THORPE SECTION

The section at Jim Thorpe is exposed in a road cut on Route 209 south, approximately 2.5 kilometers west of Route 903. An active spring emerges from the outcrop and here, the beds strike an average of N82°E and dip at an average of 45° to the south.

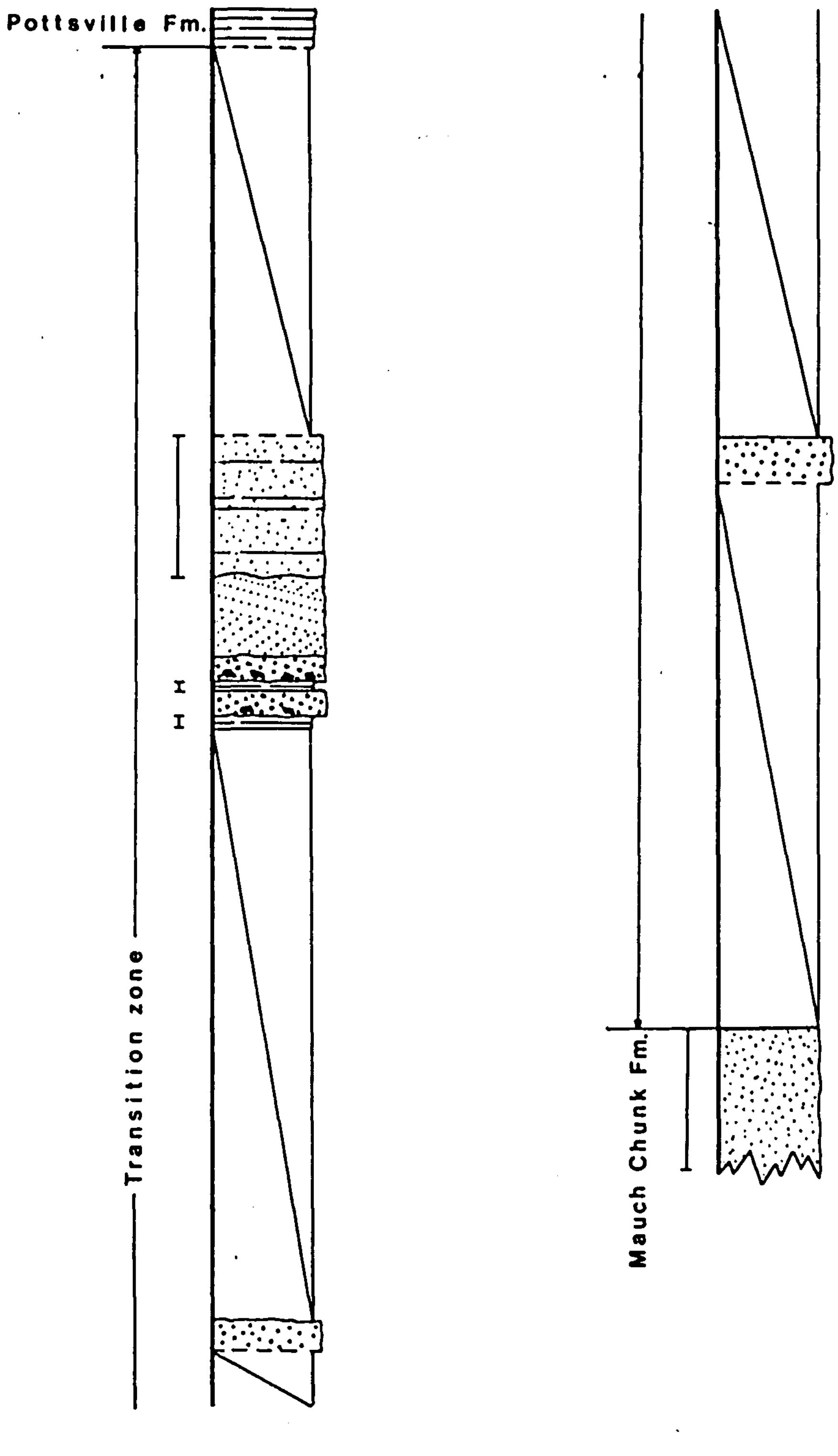
JIM THORPE



SECTION 4 - WYOMING LACKAWANNA SECTION

The Wyoming Lackawanna Section is partially exposed on the slope above Route 29 north, approximately 2 kilometers north of the Route 11 intersection in West Nanticoke, Pa. The Mauch Chunk is exposed in Harvey's Creek next to Route 29. Part of the section can be seen in a cliff above the road.

WYOMING-LACKAWANNA



VITA

Jeffrey Crane Griesemer was born on May 9, 1950 in New York City. He is the son of Dr. and Mrs. Laurence C. Griesemer of Westfield, New Jersey.

Mr. Griesemer graduated from Westfield Senior High School in June, 1969. He received an Associate of Arts degree with honors in Liberal Arts in May, 1973 from Somerset County College, North Branch, New Jersey. Mr. Griesemer entered Kean College of New Jersey in August, 1974 and in June, 1976 he was awarded a Bachelor of Arts degree, summa cum laude, with a major in Earth and Planetary Environments.

During the summer of 1975, Mr. Griesemer attended Indiana University's Geological field camp which is based in Cardwell, Montana.

In the fall of 1976, Mr. Griesemer began study towards a Master's degree in Geological Sciences at Lehigh University.