GENERAL AND NATURAL GAS GEOLOGY OF THE CALIFORNIA QUADRANGLE
WASHINGTON COUNTY, PENNSYLVANIA

Senior Thesis submitted in partial fulfillment of the requirement
for the degree of Bachelor of Science in Geology.

by

Mark VerMeulen

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Thesis Advisor: Dr. R. J. Anderson
Dept. of Geology and Mineralogy

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I. INTRODUCTION

The area of study in this report is a quadrangle located in southwestern Pennsylvania. Specifically, the California Quadrangle is located in the eastern part of Washington County, but also includes small areas west of the Monongahela River in Fayette and Westmoreland Counties (figures 1 & 2). Geologically, the California Quadrangle is located in the northern portion of the Appalachian Basin.

The original incentive to choose this area for a senior thesis came from a small oil and gas company called Pominex. I had a five week internship with Pominex during the summer of 1984. It was during this time that I first became interested in California Quadrangle and its gas production. Pominex Inc. has drilled several wells within the boundaries of the California Quadrangle. Production from these wells has ranged from good to totally unacceptable yields. Pominex does not know why the production has been so sporadic. Thus, it is the intention of this report to perhaps gain some insight into their problem, and along the way, learn some of the "basics" about southwestern Pennsylvania's oil and gas geology.

II. PALEOGEOGRAPHY AND GEOLOGIC HISTORY

CAMBRIAN

The Cambrian period, in what is now known as western Pennsylvania, is a history of a sea transgressing westward and northward over the Precambrian surface. The sands and muds deposited in this sea were derived from the north and northwest rather than from southeastern Appalachia as many suspect. The Appalachia land mass probably came into existence during the Taconic orogeny. Until this orogeny it is likely that the Cambrian and early Ordovician seas were simply an extension of a large ancient ocean (Wagner, 1966).

According to Thomas (1955) the source for the sediment deposited in western Pennsylvania during the lower Cambrian was Applachia. Whether the source was to the east or north, both Wagner and Thomas agree that during Cambrian time western Pennsylvania was covered by a shallow sea that was transgressing. They also agree that there were land masses to the southeast (Applachia?) and to the northwest.

ORDOVICIAN

There is no hiatus marking the change from Cambrian to Ordovician. Wagner (1966) states that the boundary is so transitional that it is often difficult to find. The seas continued to transgress into Ordovician time. Thomas (1955) believes that the deepest part of this sea was a northeasterly trending trench, or trough, which ran through central Pennsylvania. He also states that the Cincinnati Arch became gently emergent in the central Ohio area, thus exposing the upper Cambrian sediments to erosion. Then, sometime during the early and middle Ordovician, there was an uplifting event. This event left what is today Ohio and western Pennsylvania above sea level, and also a large east west trending strip of sea floor exposed in the Ontario area. The areas exposed were of low relief, thus allowing relatively pure limestone to be deposited in eastern Pennsylvania (Thomas, 1955). Wagner (1960) believes that this uplifting event occurred during the early Ordovician, whereas Thomas(1955) states that the event may have occurred at the beginning of the Middle Ordovician. But, Thomas (1955) does note some occurrences of sands which could be of Middle Ordovician age in Ohio. Thus Thomas himself admits slight uncertainty in his theory. At any rate there was undoubtably an area, as formerly described, which was above sea level near the boundary between Lower and Middle Ordovician.

During the Middle Ordovician the land mass described above began to submerge and the sea began transgressing westward. This marked the beginning of a long period of marine environment for the western Pennsylvania area. The majority of rocks deposited during the Middle Ordovician were limestones, with some shales. There was a major orogenic event which occurred to the east during this time . This event produced the Taconic Mountains which caused much of the sedimentation in eastern Pennsylvania to change from limestone to clastics. Thomas (1955) believes the reason these clastics did not reach the western and central portions of the state in appreciable quantities was because of the barrier action of a structure called the Adirondack arch. This structure roughly paralleled, but was just east of, the present day Allegheny front.

The sediments deposited during the upper Ordovician in western Pennsylvania were predominantly clastic due to the intense erosion of the Taconic mountains. The coarsest sediment was deposited to the east, and gradually became finer to the west. A second Ordovician uplift occurred to the southeast of central and eastern Pennsylvania during the transition from the Maysvillian to the Richmondian stage. During this time sedimentation in western Pennsylvania was predominantly shale. But towards the upper portion of the Richmondian stage the shales began to alternate with sandstones (Thomas, 1955).

SILURIAN

Clastic sedimentaion from the Taconic land mass continued into the Applachian trough during the Silurian. This trough was occupied by a shallow epicontinental sea which extended from what is now western New York to Alabama.

During the first part of the Silurian there was a regression which caused deposition of sandstones, shales and redbeds in western Pennsylvania. Following the deposition of these coarse grained redbeds, called the Grimsby (Thomas, 1955), there was a major transgressive episode. During this period the Grimsby sediments were covered by gray sand, shales and some limestones, indicating a deeper water environment.

This period of rather intense deposition was followed by decrease in the sedimentation rate during the upper portion of the lower Silurian. This decrease was probably a direct result of the decreasing relief on the land mass to the south and east. It was during this time that the Clinton Group was deposited, consisting of shales with interbedded sandstones, plus limestone and dolomite in some areas.

Above the Clinton group there is a thick sequence of dolomite and in some areas limestone. This unit was deposited during the first part of the upper Silurian and represents the largest expanse of the Silurian sea. This sea extended from western New York and Pennsylvania through the Great Lakes region and into the upper Mississippi valley.

During the later portion of this period the large epicontinental seas began to withdraw and arid climates dominated the Pennsylvania area. Thus the upper part of the Silurian in western Pennsylvania is represented by sediments containing abundant evaporites.

DEVONIAN

The boundary between the Silurian and Devonian is marked by an unconformity in western Pennsylvania(Fettke, 1953). During the early Devonian a long narrow sea stretched from the Maritime provinces of Canada to the Gulf of Mexico. Willard(1939) states that this narrow sea followed the great Applachian geosyncline, which was located just west of the coast of ancient Applachia. During middle and upper Devonian time this sea obtained its maximum proportions, reaching from Alaska and the southern arctic region through the Cordilleran region and covering most of the present day central United States (Willard,1939). As the end of the Devonian period was approached the narrow northern end of the

Applachian geosyncline became filled with sediments and the sea began to shallow appreciably. Thus the conditions which existed throughout the Mississippian and Pennsylvanian were beginning to be established.

MISSISSIPPIAN

During the early portions of the period there existed a shallow sea which probably had strong currents. These currents are indicated by the crossbedding in the sandstones and the irregularity of the shales. Hickok and Moyer(1940) believe that this period was followed by a brief uplift which brought some aeolian action to the unconsolidated sands. Then the seas moved back in and the Loyalhanna limestone, which in many places is really a sandstone, was deposited. Hickok and Moyer (1940) theorize that the calcium carbonate cement present in the sandier portions of the Loyalhanna is due to evaporational deposition during frequent atmospheric exposures.

This sequence is followed by the deltaic depositions of the Mauch Chunk formation. The source of these deposits was to the east thus the Mauch Chunk tend to thin westward. And indeed this unit does show thinning through both Fayette and Washington counties. There was a break in the deltaic environment in western Pennsylvania during which the Greenbrier limestone was deposited. This was followed by more deltaic type deposition.

The final event of this period was the retreat of the sea which produced an rather large localized unconformity. This unconformity marks the Mississippian-Pennsylvanian boundary. The exposed land mass included western Pennsylvania, eastern Ohio and northern West Virginia (Fettke,1953).

PENNSYLVANIAN AND PERMIAN

These periods are characterized by deposits which show great lateral and vertical variations. There are abundant stream deposits from sandstone to conglomerate, fresh water limestone, sandstone, shale and many coal beds. The Pennsylvanian and Permian periods in western Pennsylvania are represented by sequences of sedimentary rocks which are characteristic of rapid and repeated changes in sea level. The sediment here still had an eastern source, the Appalachian land mass. By middle Permian time western Pennsylvania was above sea level and exposed to erosion. The next major event to effect the region was the Applachian Revolution.

APPALACHIAN REVOLUTION

This great orogeny occurred at the end of the Paleozoic era. According to Hickok and Moyer (1940) this event was due to the weight of the thick sedimentary section that had been deposited in the region since Cambrian time. What ever the cause, this event occurred over a period of millions of years and produced the structures that dominate the eastern portion of the North American continent today.

III. STRATIGRAPHY

The stratigraphy in this section and the one that follows, on producing horizons, is presented beginning with the youngest strata and progressing to the oldest. This format was chosen because it represents the drillers perspective. That is when a well is drilled, the stratigraphic order progresses from youngest to oldest.

The stratigraphy presented in this report was compiled using a stratigraphic correlation chart of Pennsylvania (plate 1) as a guide. Comprehensive stratigraphic information was available for the California quadrangle from the areas Quaternary deposits to the base of the Pennsylvanian Conemaugh group. Below this a majority of the information was extracted from publications embracing the areas surrounding the California quadrangle although there were bits and pieces of subsurface data available that fell within the boundaries of the concerned quadrangle.

QUATERNARY

There is Pleistocene alluvium located throughout the quadrangle along the Monongahela River and it's tributaries. The sole Pleistocene representative is called the Carmichaels formation and is generally poorly sorted and unconsolidated. This alluvium contains a wide assortment of clastics from clay and siltsized particles to boulders with diameters upto four feet. Lenses of nearly pure clay and sand are common throughout the formation. The maximum known thickness of the Carmichael Formation is 150 feet and the units range is from zero to 150 feet.

PERMIAN AND PENNSYLVANIAN

The youngest strata in the California quadrangle is called the Dunkard group and is lower Permian in age. The Dunkard group is composed of two formations, the youngest being the Washington and the oldest the Waynesburg.

Only the middle and lower members of the Washington formation are represented in the area. The upper portion of the middle member is predominantly massive, light gray to brown, fine grained sandstone. The lower portion of this unit is predominantly gray mudstone and siltstone, which commonly contains siderite nodules. Several sequences of limestone exist throughout this middle member, ranging in thickness from 2 to 20 feet. The first section of the lower Washington is a light to dark gray , argillaceous, freshwater limestone ranging in thickness from 10 to 15 feet. This unit is followed by a section of mudstone and shale averaging about 5 feet in thickness. In this section is the Washington coal bed, whose lower boundary marks the bottom of the Washington group. The coal bed is thin and persistent. Total thickness of the Washington formation in the California quadrangle averages about 145 feet (Schweinfurth, 1967).

The second formation in the Dunkard group, the Waynesburg formation, includes the Permian-Pennsylvanian boundary. This boundary can only be located generally due to the intense lateral and vertical facies variations which exist within the Waynesburg strata. These variations were caused by rapid and continuous fluctuations in sea level during the deposition of the Waynesbug

Formation. According to Tochtenhagen (1984) the boundary is located somewhere between the Little Washington coal and the Waynesburg coal, which is represented by about 150 feet of strata (plate 1).

The upper member of The Waynesburg is composed of mudstone and shale which grade laterally into silty mudstone and very fine grained sandstone. At the base of this unit is the Little Washington coal bed, which is persistent and ranges from 2 to 4 feet in thickness. The middle member is composed predominantly of mudstones which contain thin beds of siltstone and fine grained sandstone. It also contains a few lenticular beds of carbonaceous shale, clayey coal, sandstone reaching 12 feet in thickness and one to three lenticular sections of limestone. The base of the middle member is marked by a coal bed called the Waynesburg "A". This unit is generally argillaceous with clay partings 1 to 5 feet thick. The lower member of the Waynesburg formation begins below the base of the Waynesburg "A" coal bed, and is predominantly mudstone. Directly below the coal bed there is a lenticular limestone unit with a maximum thickness of approximately 3 feet. Towards the bottom of the lower member the mudstone tends to grade into a massive, fine to medium grained sandstone. The base of the Waynesburg formation is marked by the Waynesburg coal bed. This coal unit reaches maximum thickness in both the northeast and southwest corners of the quadrangle, maximum thickness being about 6 feet. The Waynesburg is commonly split into two sections by as much as 16 feet of mudstone. This unit is an important resource in the north east and south west corners of the California Quadrangle. The original Waynesburg coal resources were approximately 29.3 million short tons (Schweinfurth,1967).

The next Pennsylvanian unit exposed in the report area is the Monongahela group, which begins below the Waynesburg coal bed and terminates at the base of the Pittsburgh coal bed. This group received its name from Stevenson (1873) who was the first to study the spectacular exposures along the Monongahela River (photo 1). The Monongahela group is composed of cyclic sequences of sandstone, shale, limestone and coal. In Green County it is approximately 330 feet thick and contains over 100 feet of limestone, whereas in the California Quadrangle the formation varies between 340 and 380 feet and contains similar thicknesses of limestone. Also in the Monongahela group are four coal units: the Uniontown, the Sewickly, the Redstone and the Pittsburgh. The most notable of these is the Pittsburgh. This unit varies from 6 to 10 feet in thickness and is uniform in both quality and thickness. It serves as an excellent marker bed (Stone, 1932; Donegal, 1963). Locally the Pittsburgh coal has been mined out.

Below the Monongahela is the Conemaugh Group which is named for its good exposures along the Conemaugh River. This group's upper boundary is the base of the Pittsburgh coal and its lower boundary is the top of the Freeport coal. The Conemaugh Group consists of sandstone, red and gray shale, limestone, thin coal beds and small amounts of low grade fire clay (Hickok and Moyer,1940). This group contains four marine zones (limestones) which are good marker beds. They are: the Ames, the Woods Run, the Pine Creek and the Brush Creek (Berg, 1984). The Conemaugh also contains five separate coal units. In the Pittsburgh

Photo 1. Strata exposed along the Monogahela River
north of Brownsville, Pennsylvania.

Quadrangle, Allegheny County the lower portion of the group thins appreciably from east (650 feet) to west (425 feet) (Johnson, 1929).

The next Pennsylvanian unit is the Allegheny Group named after exposures along the Allegheny River north of Pittsburgh. The upper boundary of this group is the top of the Freeport coal and the lower boundary is the top of the Homewood Limestone. The Allegheny group consists of limestone and sandstone with lesser amounts of fire clay and coal. The Upper Freeport and the Lower Kittanning are the coal units. The Upper Freeport is from 3 to 4 feet in thickness and is very consistent through out western Pennsylvania. The Lower Kittaning coal shows good purity and consistency over short distances and varies from 2 to 5 feet thick (Hickok and Moyer, 1940). Other notable marker beds are the Johnstown (freshwater) Limestone and the Vanport Limestone (Berg, 1981). In Fayette County the Allegheny Group's thickness varies between 160 and 230 feet (Hickok and Moyer, 1940).

The final division of the Pennsylvanian is the Pottsville Group. Its upper boundary is the top of the Homewood Sandstone (Hickok and Moyer,1940) and its lower boundary is the top of the Mauch Chunk Formation, which is an unconformity. This unconformity also represents the Pennsylvanian-Mississippian boundary. The magnitude of this unconformity can be appreciated when one compares the 200 to 300 feet of Pottsville strata in western Pennsylvania to the 3850 and 9000 feet of Pottsville equivalents in southern West Virginia and northern Alabama, respectively (Fettke, 1953).

The Pottsville group is composed largely of massive,

Photo 2. Waste coal left from an old mining operation along Interstate 77, just west of Lover,Pennsylania.

Photo 3. Shale showing small scale folding near California, Pennsylvania on route 88.

Photo 4. Sandstone outcrop along route 88 north of Coal City, Pennsylvania.

Photo 5. Coarse grained, micaceous sandstone exposed along Route 40, 5 miles west of Brownsville, Pennsylvania.

Photo 6. Close up of the sandstone in photo 5.

irregularly bedded sandstones. They are white to various shades of gray, fine to coarse grained and in some areas tend to be conglomeratic. The sandstones are commonly separated by thin beds and lenses of silty shale. In the middle section of this group are three coal beds. Two, the Lower Mercer and the Tionesta, are very thin and of poor quality. The third called the Upper Mercer is of fair to poor quality and varies from 1 to 4 feet in thickness (Stone, 1932).

MISSISSIPPIAN

This system outcrops in the eastern portion of Fayette County, thus many of the descriptions that follow were taken from Hickok and Moyers publication on Fayette County. Some descriptions and other data were available from McGlades (1967) report on the Amity and Claysville quadrangles. This area is located only ten miles or so from the California quadrangle (figure 1) so it was considered to be the most reliable reference.

As stated earlier the top of the Mississippian in southwestern Pennsylvania is marked by an unconformity between the Pottsville Group and the Mauch Chunk Formation. The Mauch Chunk can be generally divided into three lithologic units: 1)An upper section consisting mostly of bright red shale with lesser amounts of green shale and buff micaceaous limestone, 2)a middle section composed of a dark fossiliferous limestone (Greenbrier Formation) with interbedded shales and 3)a lower section consisting of red and green shales and olive micaceous sandstone. McGlade (1967) refers to the Mauch Chunk Formation as the Greenbrier Group and notes that the lower section of shale and sandstone is totally absent in Claysvilly and Amity Quadrangles. The base of the Mauch Chunk (Greenbrier Group) is represented here by the Greenbrier Limestone which is a very fine, dark argillaceous limestone. The Greenbrier Limestone of Amity and Claysville Qaudrangles rests directly on the Loyalhanna Formation. The Loyalhanna is a very fine grained, gray calcareous sandstone (McGlade, 1967). Hickok and Moyer (1940) note that in Fayette County this unit contains calcitic oolites and shows local secondary silicification.

Below the Loyalhanna Formation is a group known as the Pocono (figure 3 and plate 1). This group is divided into three general sections by Hickok and Moyer (1940). The youngest unit is the Burgoon Sandstone is commonly called the "Big Injun". This unit can be differentiated from the overlying Loyalhanna because it is coarse grained and the grains are substantially more angular. It also contains muscovite and lacks the carbonate cement which is characteristic of the Loyalhanna (McGlade, 1967). The second unit, called the Cuyahoga shale by Hickok and Moyer (1940), is a thick shale unit. McGlade (1967) states that a 50 to 60 foot thick shale unit follows the Loyalhanna in eastern Amity Quadrangle, which is followed by a sandstone unit called the Squaw Zone. The Squaw zone, a drillers' term, is composed of an upper and a lower sandstone which are separated by a thin layer of shale. In eastern Amity Qaudrangle this sequence is 75 feet thick, but to the west in Claysville Quadrangle the the Squaw thins to only 10 feet in thickness. Below the Squaw Zone is another shale unit which becomes increasingly complicated with interbedded sandstones downwards (figure 4). At the base of lower shale section is a sandstone unit called the Murrysville

(McGlade,1967). So Hickok and Moyers' (1940) Cuyahoga shale is composed of and upper shale unit, a central sandstone unit (Squaw Zone) and a lower unit of shale and interbedded sandstone, the base of which is the Murrysville Sandstone. The last division in the Pocono, the Murrysville, is a grayish fine grained sandstone. By examination of figure 4 the Murrysville unit seems to vary between 25 and 30 feet, and it is the base of this sand which marks the lower Mississippian boundary. Thickness from the base of the Squaw zone to the base of the Murrysville is between 275 and 300 feet in eastern Amity Quadrangle. Total thickness of the Pocono Group just east of the California Quadrangle is about 600 feet (McGlade, 1967).

DEVONIAN

The Upper Devonian is a rather complex section of strata because of the lithofacies variations which are represented by intense interbedding between the sandstone and shale units. Also complicating the matter is the wide array of stratigraphic terminology used to describe the Upper Devonian strata. Thus the divisions presented here are rather general, but seem to be quite adequate (figure 5).

The Upper Devonian can be divided into two groups, the youngest is the Catskill Group and the oldest is the Chemung Group. Where the upper limit of the Catskill Group meets the lower limit of the Mississippian's Murrysville Sandstone is the Mississippian-Devonian boundary. This boundary is transitional, but can be generally located by the bright red color characteristic of the Catskill Group. The strata in the Catskill also becomes temporarily more shaley than the overlying Murrysville unit.

The Catskill Group is composed predominantly of red reddish gray, and greenish gray shales with occasional thick sandstone beds. The sandstones are fine to medium grained and composed of subangular quartz and interstitial clay (Richardson, 1934). These sandstone beds are very productive gas horizons in the eastern Washington County area, and will be discussed in in a section to follow. In eastern Somerset County the Catskill Group is 1800 to 2000 feet thick. Edmunds and Berg (1971) note that in eastern Clearfield County the Catskill is 1200 to 1400 feet thick, where in the western part of that county the unit thins to 400 feet. Hickok and Moyer (1940) say the Catskill Group ranges from 350 to 450 feet in thickness in Fayette county. So the Catskill sediments definitely thin to the west, and in fact, according to Jones and Cate (1957) the western limit of the Catskill deposition passes through central Washington County from north to south.

The boundary between the Catskill and the Chemung Groups is transitional, thus it is sometimes difficult to locate. The most widely used marker is again the red color of the Catskill Group. Richardson (1932) claims that the two groups can be separated by using paleontological data, but his predecessors do not seem to agree with him. The Chemung Group is predominanty shale. The upper portion does have considerable sandstone thickness, but the lower portion is almost exclusively shale. The upper section's sandstones are greenish gray in color, fine grained and arkosic. The shales in this section tend to have the same coloring with an occasional reddish layer and are commonly silty to sandy. The lower shales tend to be darker in color and are calcareous. In plate 1 the lower section of the Upper Devonian is given different names by Borg. Specifically the Rhinestreet Shale, the Sonyea Formation and the Genesse Formation. But for the purpose of this paper it seemed adequate to call the whole section Chemung (Figure 5) as was done by Henderson and Timm (1985). In western Clearfield County the Chemung ranges from 4900 to 5100 feet in thickness, and Hickok and Moyer (1940) estimate the group's thickness to be around 5300 feet in Fayette County.

The division between the Upper and Lower Devonian is marked by the top of the Tully Limestone. This unit is very consistent and is used as a marker bed by drillers. The Tully Limestone is argillaceous and fossiliferous (Cate, 1953). It is commonly light gray, noncrystalline and shows some layering which averages about 2 inches in thickness. In many places the limestone layers are separated by thin shale partings (Willard, 1939). Some suggest that a disconformity exists between the Chemung and the Tully. And Cate (1963) supports this idea but only on a local scale. Hickok and Moyer (1940) estimate the Tullys average thickness in Fayette County to be 95 feet.

The Tully Limestone becomes silty as it grades into the Hamilton Group. This group is composed of two formations: the Mahantango and the Marcellus. The Mahantango Formation includes all the members of the Hamilton Group which are coarser than shale, where the Marcellus Formation is composed of three types of shale: medium gray calcareous shale, dark gray slightly calcareous shale and silty to carbonaceous shale (Cate, 1963). These two formations intertongue with each other throughout the Hamilton

Group though generally the Mahantango tends to dominate the upper portion of the group, where the Marcellus prevails in the lower portion (Cate, 1963). Hickok and Moyer (1940) estimate the Hamilton Group's average thickness in Fayette County to be around 575 feet. Cate (1963) claims the group's thickness is only 350 feet in Amity Quadrangle.

Underlying the Hamilton Group are the sediments deposited during the Onesquethaw Stage. The strata representing this stage are the Onondaga Limestone, the Huntersville Chert and the Needmore Shale.

The youngest of these divisions is the Onondaga Limestone. According to Dennison (1961) it is a cherty limestone and should only be classified as Onondaga if the carbonate percentage exceeds that of the chert. This unit is restricted to the western part of Pennsylvania. In Washington and Fayette Counties the Onondaga is very thin, having a maximum thickness of 5 feet. This cherty limestone grades into the Huntersavelle Chert. The boundary is taken to be the point at which the strata contains more chert than carbonate. Not far from this boundary the Huntersville becomes a relatively pure, noncalcareous chert. Both glauconite and pyrite are common in this unit suggesting deposition in a reducing environment. Because the Huntersville Chert occupies such a large area, it is likely that it is a primary deposit, as opposed to being a product of secondary silicification, which tends to effect comparatively small areas. The thickness of the unit in the California Quadrangle area varies form 100 to 150 feet decreasing in thickness from the southwest to the northeast. And finally, the Needmore Shale is commonly dark and very fine grained in the area of Washington and Fayette counties. The Needmore varies from about 10 to 30 feet in thickness, decreasing from the east to west in the California Quadrangle area (Dennison,1961).

Located somewhere in the Huntersville Chert is the Middle-Lower Devonian boundary. This boundary is transitional and very difficult, if not impossible, to define.

Below the Needmore Shale is the Ridgeley Sandstone, which is better known as the Oriskany Sandstone. This Lower Devonian sandstone is predominantly calcareous, but sometimes grades laterally into an arenaceous limestone (Willard, 1939). This limestone is called the Licking Creek Limestone and it usually occurs in the lower section of the Oriskany. The Shriver Formation, which commonly underlies the Oriskany or Licking Creek, becomes totally absent to the east of the California Quadrangle area in central Somerset County. The Oriskany averages about 75 feet in thickness throughout the area of this report and begins to thicken appreciablly in central Fayette County.

Below the Oriskany and the Licking Creek is a group of sediments deposited during the Helderbergian Stage.The upper most unit is called the Mandata Shale, which is followed by two limstone units: the Corriqunville and the New Creek Limestones. Hickok and Moyer (1940) estimate that this group of strata averages 350 feet in Fayete County, where in the California Quadrangle area the Helderbergian units range from 270 to 300 feet thick, decreasing from south to north (Jones and Cate, 1957).

SILURIAN

Underlying the Helderbergian strata is a formation called the Keyser. It is in the upper portion of this formation that the Devonian-Silurian boundary is located. Thus in southwestern Pennsylvania the boundary can only be defined generally (Cate, 1965). The Keyser Formation is thought to be the time equivalent to the Bass Island Group in northwestern Pennsylvania. The Keyser is composed primarily of dark to light grayish brown, medium to finely crystalline limestone. The thickness of the limestone in the California area ranges from 125 to 150 feet and is relatively consistent (Cate, 1965).

Below the Keyser Formation is the Salina Group which is an interbedded sequence of dolomite, dolomitic shale, anhydrite and salt.The Salina Group generally thins from southeast to northwest. According to cross sections produced by correlating well log data, the Salina Group shows thicknesses approaching 1000 feet in the California Quadrangle area, with a regional south to north thinning trend (Cate, 1965).

The deepest well data available for the California Quadrangle region reached about 8000 feet. Both of the wells that went this deep terminated in the Salina Formation. If detailed stratigraphy for the strata below this is desired it must be inferred from outcrops and well data in the northern, central and eastern parts of the state. Cate (1961) did make two inferred cross sections of the Silurian which included the northern portions of Washington and Fayette Counties. Examination of these cross sections reveals the great need for more deep well data in southwestern Pennsylvania. Therefore, I decided not to try and speculate about stratigraphic descriptions for the units below the

Silurian Salina Group. Figures 6 through 11 show rough sketches of isopachs for some of these units as presented by Thomas (1955). Major stratigraphic divisions can be found in plate 1, and if more detailed descriptions are desired for the units below the Silurian Salina Group in northwestern Pennsylvania, Wagner's 1973 publication should be consulted.

V. STRUCTURE

The California Quadrangle is located in the Appalachian Basin, in the western part of the Allegheny Plateau. The folded Appalachian Mountains have a complex structure, while the basin area's structural geology is comparatively simple.

The entire area of western Pennsylvania has a shallow southeasterly regional dip. This is accompanied by gentle symmetrical folds which trend southwest to northeast. Specifically the California Quadrangle has two synclines and one anticline located within its boundaries (Plate 3). The anticline is called the Bellevernon, and its axis enters the quadrangle in the southwest corner and exits slightly west of the northeast corner. The axis of the Port Royal Syncline cuts across the southeastern corner of the quadrangle and the axis of the Waynesburg Syncline cuts across the northwest corner of the quadrangle. By examining the cross section (Plate 4) of the area the broad and symmetrical nature of the folds can be seen.

No major faulting is known to exist in the area, but certainly there is local faulting, jointing and fracturing with the boundaries of the California Quadrangle. In fact, subsurface fractures and fracture systems are now believed to be a major controlling factor in the migration of hydrocarbons in the Appalachian Basin. This subject is discussed further in the section of this report intitled Production Horizons.

V. OIL AND GAS HISTORY

In 1821 a well was drilled in Freedonia, New York to supply the town with natural gas to light the city streets. This sparked some drilling activity along the shores of Lake Erie in New York, Ohio and Pennsylvania. This gas was only used locally because there was no way to transport it due to the lack of steel pipe. It was not until 1859 that the single most remembered event in the history of the United States petroleum industry took place. This was the drilling of the Drake #1 by "Colonel" E. L. Drake on the outskirts of Titusville, Pennsylvania. Oil was discovered 67.5 feet below the earth's surface (Miller, 1968). This was the first oil well in the U.S. and it set the oil industry into motion.

The California Quadrangle has produced gas for more than 93 years, from sandstone zones in the Lower Mississippian and Upper Devonian (Schweinfurth,1967). Oil production in the area has been very limited; of all the completion reports viewed by the author only a few reported oil shows and none reported producible quantities. While the gas production from this area by no means is in the same league as the northwestern counties of Pennsylvania, an example of a tremendous well, located in the California Quadrangle, is the Rider #1. This well was drilled in

1903 and is over 82 years old. In 1976 it was still producing over 3500 MCF per year and showing a general increasing trend (Figure 12). Another great well is the Sproals #1, located just outside the quadrangle's boundaries near the Crow and Hess wells shown on Plate 4. The Sproals was drilled in 1945 and in 1976 the well produced 6502 MCF. These two wells are probably among the best the area has ever produced. So, indeed, there is gas in the area; it is just a question of drilling in the right location.

VI. PRODUCING HORIZONS

Because the California Quadrangle's gas production at present comes predominantly from the sands of the Lower Mississippian and Upper Devonian, these units will be the focal point of this report's section on production. Aiding this decision was the fact that all the well log data available to the author,except those in publications, had a maximum penetration depth of about 4100 feet, and the next lower producing horizon is is the Oriskany at about 8000 feet. Following the discussion of Lower Mississippian and Upper Devonian production a section will be presented on production and production potential of the strata above and below the Mississippian-Devonian group.

LOWER MISSISSIPPIAN AND UPPER DEVONIAN PRODUCTION

Harper, Laughray and Lytle (1982) list two gas fields and three gas pools which are located, at least partially, within the boundaries of the California Quadrangle. The first field is the

Bellevernon, discovered in 1887, which produces mainly from the Upper Devonian sands (plate 5), but also has minor prodution from the Oriskany Sandstone of the Lower Devonian. The second field is the Brownville,also discovered in 1887, which produces from the Mississippian sands (Big Injun and Murrysville) and from the Upper Devonian sands. The first gas pool is the Lover, discovered in 1968, which produces from the Oriskany Sandstone. The second pool is the Granville, discovered in 1976, which produces from the Upper Devonian sands, and the last pool is the Coal Center, discovered in 1978, with production coming from the Mississippian sands.

Examination of temperature logs for several wells in the California Quadrangle revealed that the gas shows came exclusively from the Upper Devonian and Mississippian strata. Temperature logs simply show the temperature in the drill hole as a function of depth. At points where gas is leaking into the drill hole the temperature log shows an abrupt decrease in temperature, thus enabling the producing horizon to be pinpointed. As stated in the history section of this paper no producible oil shows were reported in the California Quadrangle area.

The Mississippian and Devonian strata contains many sandstone units which have produced gas in the California Quadrangle since before the turn of the century. Plate 2 shows the individual sand units with the driller's names. Piotrowski (1980) believes that the driller names for these sands represent noncontinuous, lenticular deposits which cannot possibly be correlated over large areas. Matteson and Busch (1944) agree as shown in Figure 13. Piotrowski (1980) suggests the classification shown in Figure 14. Indeed this is probably a much better way to classify these sand units, but considering that the area covered by this report is small the established terminology (Plate 2) seems quite appropriate.

From this point on, all the sands between the top of the Big Injun and the bottom of the Bayard Zone will be referred to as the Venango Group (after Harper, Laughtrey and Lytle, 1982). The uppermost sand unit in the Venango Group is the Big Injun. McGlade (1967) states that the Loyalhanna and the Big Injun are really two separate units, as seen in plate 2, but this report will use the driller's term, which classifies the whole section as Big Injun. The upper portion of this unit is a fine grained, non-calcareous sandstone with predominantly rounded grains. This upper section grades into the lower section which is a medium grained, angular, non-calcareous sandstone which is poorly sorted (McGlade, 1967). Thickness of the Big Injun in the California Quadrangle is about 250 feet.

Production from the Big Injun has been almost solely gas although McGlade (1967) does note a very local oil field in Amity Quadrangle in which the discovery well produced 700 BOPD in 1886. Of the wells used in this report only thirteen had temperature logs available, and of these thirteen the Hess #1 showed gas at the base of the Big Injun.

The Squaw Zone, the next sand below the Big Injun, is a very fine to fine grained subangular sandstone containing some medium sized quartz grains (McGlade,1967). The Squaw varies between 80 and 140 feet in thickness throughout the California Quadrangle. The Campana #1, the Kulikowski #1, the Skouran #1 and the Harris #1 produced gas from the Squaw Zone, which was discovered by examination of the temperature logs.

The Squaw Zone is followed by the Upper Thirty Foot Zone, which includes the Murrysville Sandstone as described in the stratigraphy section. McGlade (1967) notes as many as seven separate sand units in the Murrysville which thin from east to west. In the logs from the California Quadrangle this zone showed a maximum of three sandstone beds, with a total thickness around 100 feet. The sandstone in the Upper Thirty Foot Zone is very fine to fine grained, subangular and slightly calcareous (McGlade, 1967). Examination of temperature logs showed that the Crow #1, the MIDA #1, the RSA #1 and the Sterbenz #1 produced gas from the Upper Thirty Foot Zone. McGlade (1967) notes that this unit only produces gas in the Amity-Claysville area. The base for the Upper Thirty Foot Zone, or Murrysville sand, marks the Mississippian-Devonian boundary.

The first unit in the Devonian is a shale which is between 75 and 100 feet thick in the California Quadrangle. This shale is followed by the Hundred Foot Zone. This zone has an upper and a lower unit. The upper unit, known as the Gantz, is a medium grained, subangular sandstone which contains pebbles. The lower unit, known as the Fifty Foot, is a very fine to medium grained subangular sandstone (McGlade,1967). In the logs examined from the California Quadrangle the Hundred Foot Zone was composed of several sandstone bodies with a total thickness, including the interbedded shale, of 90 to 150 feet. Almost all of these logs showed three prominent sandstone beds, each being about 20 feet thick. The Crow #1, the Taylor #2, the MIDA #1 and the Deems #1 temperature logs indicated gas production in the Hundred Foot Zone. In the California Quadrangle the only gas production is known to come from the Hundred Foot Zone, but McGlade (1967) notes that this unit has produced oil and gas in the Amity-Claysville area. In fact he states that this zone is the most prolific producer of oil in the area. It can only be speculated why this is not true in the California area. Perhaps it is caused by a westerly dip or possibly a group of fractures has locally effected migration.

The Hundred Foot Zone is followed by the Nineveh Zone. These two zones are separated by a consistent 20 to 30 foot shale break on the logs. The Nineveh is a of very fine grained sandstone. In the Amity Quadrangle the Nineveh is a very minor source of gas, commonly part of the production from multi pay wells (McGlade, 1967). The Nineveh in the California Quadrangle is about 20 feet thick and shows consistency throughout the area. The Winnett #1 showed gas at the Nineveh on its temperature log.

The next sand is the Gordon Zone, which is a fine to coarse grained sandstone. North of the California Quadrangle this unit is slightly conglomeratic. The unit is called complex by McGlade (1967) due to the interbedded shale. He estimates the thickness between 75 and 100 feet. This report will consider the Gordon to be a sandstone unit about 30 feet thick which showed up consistently on logs. There are about 50 feet of siltly sand and shale above and below the Gordon Zone. In Amity and Claysville Quadrangles there has been some oil production from the lower section of silts and shales. Due to a lack of temperature logs and completion reports none of the wells included in this report are known to produce gas from below the Gordon Zone, with the exception of the Campana #1, which had a minor show in the Fifth Sand. It seems very likey that there is gas below the Gordon Zone in California Quadrangle, simply because McGlade (1967) notes ample gas production from the Gordon and many of the sands below.

The Fourth sand follows the Gordan Zone. This unit is a very fine grained silty sandstone with an occasional section of rounded pebbles (McGlade, 1967). In the logs the Fourth Sand shows up as three or four sandstone beds with thicknesses ranging from 2 to 30 feet. The unit's total thickness in the California Quadrangle ranged from 30 to 110 feet and showed a westward thinning trend. McGlade (1967) calls this a zone of interbedded sandstone, siltstone and shale with a maximum thickness of 75 feet in the eastern Amity Quadrangle. He states that the Fourth Zone is nonproductive at present, but has produced oil and gas in the past in the Amity Quadrangle.

Below the Fourth is the Fifth Zone. This unit is a fine to coarse grained sandstone with an occasional pebbly conglomerate facies. In the Amity and Claysville area McGlade (1967) states that the Fifth is an important source of gas with some slight oil production. The unit is consistent throughout Amity and the eastern portion of the Claysville Quadrangle. This unit is also consistent in California Quadrangle showing a thickness of 20 feet in all areas. As stated previously the Campana #1 had a small gas show in the Fifth along with major production in the lower Squaw.

Below the Fifth is the Fifth "A" Zone. This Zone has two sand units with a thick shale separation between them. No detailed lithology was available for the unit. Its thickness is

50 to 75 feet, with the greatest thickness being in the eastern part of the quadrangle.

The last section is the Bayard Zone. According to McGlade (1967) this zone consists of very fine grained siltstones and shale. In the California Quadrangle the logs showed two consistent, but thin, sandstone units along with the strong shale readings. The total thickness of the two sands was about 10 to 15 feet and the total thickness of the zone is between 40 and 50 feet. McGlade (1967) calls the Bayard Zone a major source of gas in the south eastern portion of Amity Quadrangle.

McGlade (1967) states that all of the Devonian sandstone units thin to the west of his area. His believes that the porosity and permeablity of these units is related to the position on an ancient offshore marine shelf. Further more he believes that if isopachs were made of the individual units (i.e. Squaw Zone, ect.) then this relationship could be deciphered. He believes this to be much more important than sand thickness. Since McGlade's (1967) paper was published a group of isopachs, which include the Upper Devonian sands, have been published by Piotrowski and Harper (1980). From examination it looks as if the zone which McGlade speaks of is located to the east of Washington and western Fayette counties, perhaps the scale on these maps is not quite small enough, but realistically it looks as if Washington and Fayette Counties were just off the edge of the shelf area where these units were deposited.

But it is this authors personal opinion that the key to successful production in the southwestern Pennsylvania area is the occurrence of natural fractures, and perhaps systems of fractures within the strata. The sands in Pennsylvania are notorious for their low permiabilities, so fractures seem to be the best alternative.

Further evidence for this is Piotrowski and Harpers (1980) Devonian shale research. Piotrowski (1980) states that natural fractures commonly serve as reservoirs in the Devonian shale. Most of the Upper Devonian sands are tight and fine grained thus they would receive and support natural fractures with little resistance. And indeed, Tillman (1982) states that "naturally occurring fracture systems are critical for production in Devonian shale and tight sand formations even where artificially stimulated, because the success of hydrolic fracturing is dependent on the interaction with natural fractures. Figure 15 shows a general view of the area effected by the fracturing. Tillman (1982) believes that the fracturea are the direct results of reactivated basement faults, multiple stages of the Alleghenian deformation and late Paleozoic and Mesozoic uplifts. And finally he states that much work needs to be done in this area to understand the relationship of these natural fractures systems to the migration and concentration of hydrocarbons. Also important is the study of the fracture systems themselves. So it seems that natural fracture systems is an area of great importance to the petroleum seekers in the Pennsylvania area, and the Appalachian Basin in general. And further more there is no reason why this control could not be extended deeper into the Silurian, Ordovician and Cambrian.

DEEPER PRODUCTION

What about the Lower Devonian, Silurian and Ordovician strata in southwestern Pennsylvania? The Lower Devonian contains three zones which are appealing: the Onondaga Formation, the Huntersville Chert and the Oriskany Sandstone. In the Onondaga Formation, a cherty limestone, reefs have been discovered in the northwestern part of the state. These reefs have yielded very high hydrocarbon production. No reefs have been found in the southwestern part of the state. The Onondaga is over 200 feet thick and contains about 50% chert in the California Quadrangle. Whether or not Onondaga reefs are likely in this area is hard to say, but Harper (1981) notes that reefs have been found in areas where the Onondaga has been comparatively thin. Futhermore, Harper continues, that even in areas where reef development is unlikely the Onondaga still has good hydrocarbon potential. The Huntersville Chert lies directly below the Onondaga and has about the same potential minus the reef production.

Below the Huntersville is the Oriskany Sandstone. This unit is 70 to 80 feet thick in the California Quadrangle and is 8000 feet below the surface. This depth seems to be the major restriction in development of the Oriskany as a gas producing horizon in southwestern Pennsylvania. Some small production in the California area has come from the Oriskany already, as stated formerly, but its potential for the future looks very good. Most of the Oriskany fields are found to the north and east of Washington County (Figure 16), probably because the sandstone is not as deep in these areas. The Oriskany's thickness in the California Quadrangle is very high relative to the rest of the state. Thus it seems that it should contain gas here, as it does in the other parts of the state. According to Harper (1981) the Oriskany and the Huntersville accounted for 85% of the state's deep well production during the 1970's. So indeed the future does look bright for production from the lower Devonian.

The Medina Group is the most attractive target in the Silurian. There is very little subsurface information about this group in southwestern Pennsylvania. Piotrowski and Harper (1981) do cite two exploratory wells drilled to the Medina in Beaver County, to the northwest of Washington County, both these wells were nonproductive. Piotrowski cites a gas pool in central Fayette County to be the only production from the Medina Group in southwestern Pennsylvania. No information was found by the author about this pool. The Medina undoubtably has great potential in the area, its just that its so deep that drilling for the Medina does not pay right now.

According to Henderson and Timm (1985) there is excellent hydrocarbon potential in eastern and central Pennsylvania from the Ordovician marine shelf deposits (Figure 17). They believe that the petroleum accumulations in these strata are in stratigraghic traps, as opposed to the structural traps common of the areas younger producing zones. This infers that the Ordovician strata in southwestern Pennsylvania is likely to be silt and clay, which reduces the likelyhood of petroleum reserves. But who knows what is really down there?

SHALLOW PRODUCTION

The strata above the Big Injun, in southwestern Pennsylvania in general, yields gas. No production data for these units was found for the California Quadrangle, nor were any reservoirs listed that produced from this zone.

The youngest zone known to produce above the Big Injun is called the Murphy Sandstone. McGlade (1967) notes that this fine to medium grained sandstone has very minor gas production in the Claysville-Amity region. Thickness is about 80 feet.

Below the Murphy are the Saltsburg and Dunkard Sandstones. The Saltsburg is not known to produce appreciable amounts of gas any where in Claysville or Amity Quadrangles. This unit thins to the west. The Dunkard sandstone is a complex group of interbedded sandstone and shale. This group of beds has produced oil in Amity Quadrangle in enough quantity to warrant production even though the wells commonly yield 50% salt water and have paraffin build up problems. Thickness averages about 200 feet throughout Claysville and Amity Quadrangles.

The next producing zones are the Upper Gas and the First Gas Sandstone. These units yield very minor amounts of gas in the Amity and Claysville Quadrangles. Their thickness varies from 0 to 75, feet and they exhibit drastic and abrupt facies changes (McGlade, 1967).

The final production horizon which overlies the Big Injun is the Salt Sandstone. This unit varies from fine to coarse grained, but is commonly medium grained and occasionally contains pebbles. The Salt is composed of two sandstone units separated by a shale bed. The most persistent bed is the lower sandstone. These two sand units have been known to produce gas for long periods except, like the Upper Gas and the first Gas, it is plagued with high salt water yields and paraffin buildup problems.

VII. CONCLUSION

The California Quadrangle has been producing gas from the Lower Mississippian and Upper Devonian since the late 1800's, with a small amount of production also coming from the Lower Devonian Oriskany. No oil production was found to exist at present in the California Quadrangle by the author.

Production from strata younger than Lower Mississippian is small and plagued by high salt water yields and paraffin buildup problems. Production from strata older than Upper Devonian is again small, but these units have great potential for the future. Exploration of the older gas bearing rocks is restricted by the cost of drilling to 8000 feet, the depth to the Oriskany, and beyond.

In making recommendations for Pominex's problem, analysis of the maps (plates 5-7) can yield areas with structural highs, maximum sand thickness and maximum porosity thickness, if in fact these are the parameters which control the degree of success of the areas gas wells. But it is the feeling of the author, and others, that successful production is dependent on natural fractures in the subsurface. This is true because the permeability of the areas' sandstones is quite low. As far as locating these subsurface fractures in the California Quadrangle, perhaps examination of topographic trends, aerial photos and satelite photos could produce some desirable drilling locations. But certianly research on locating fractures and their effects on migration and accumlation will progress over the years to come and hopefully help to solve Pominex's problems in the California Quadrangle area.

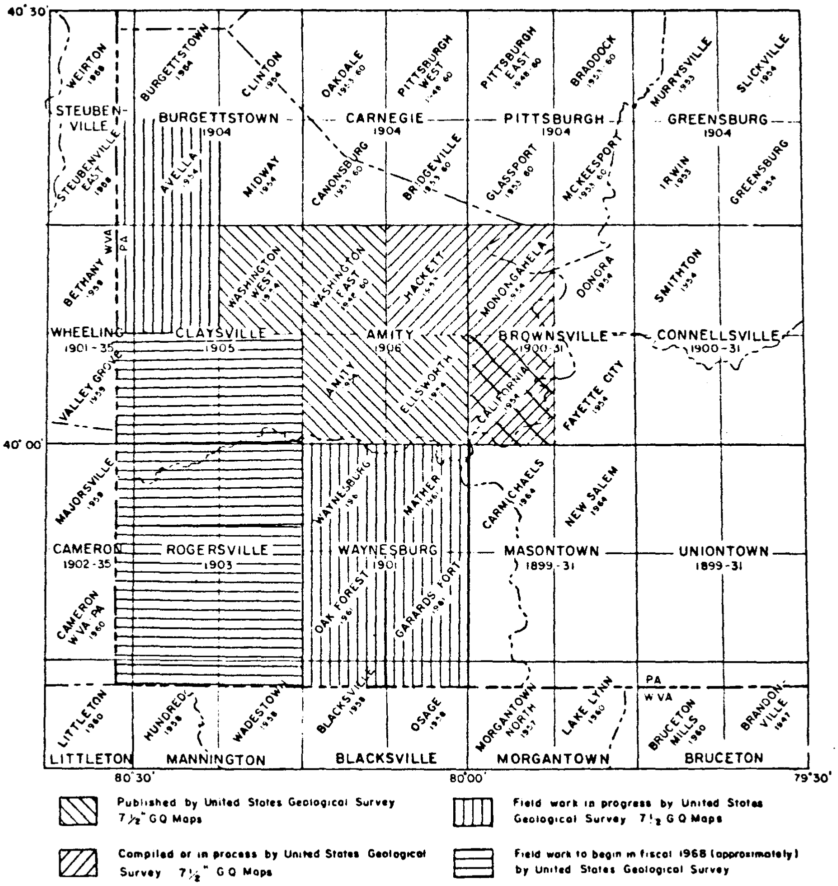


Figure 1. Location of the California Quadrangle (McGlade, 1967).

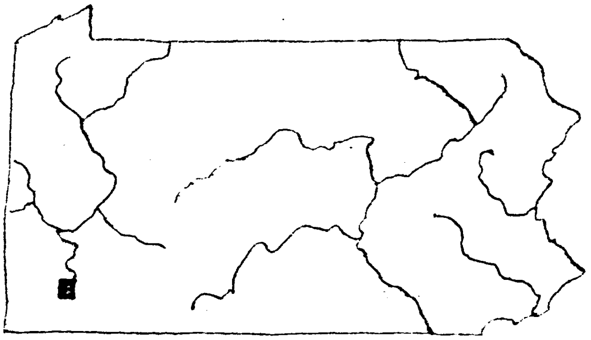


Figure 2. Location of the California Quadrangle with respect to the state of Pennsylvania.

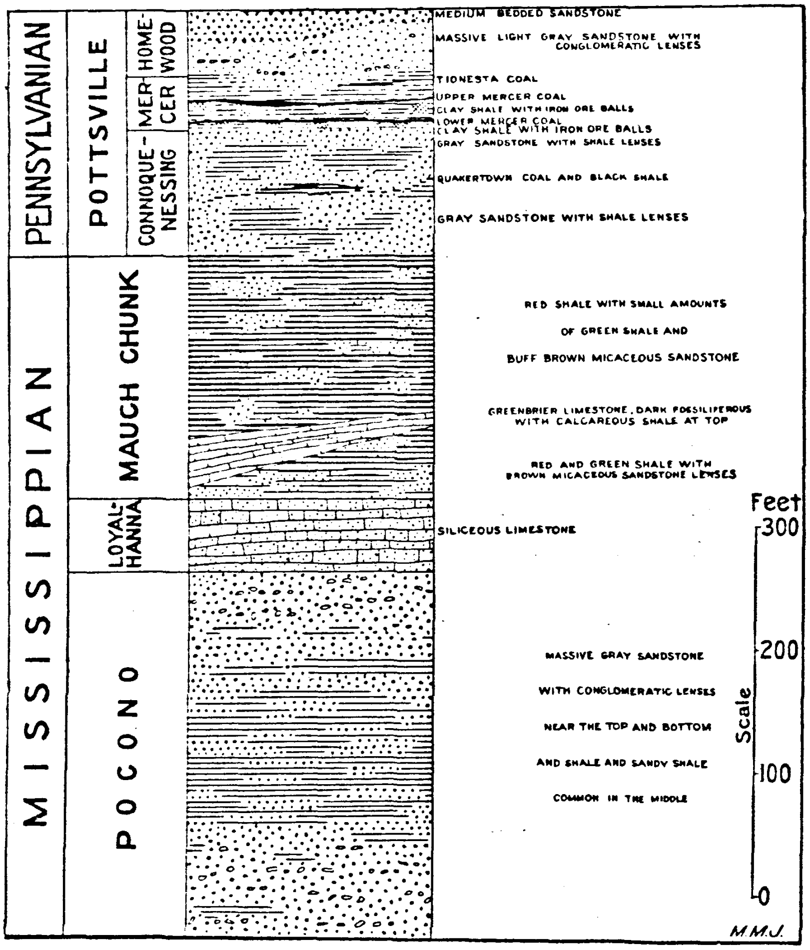


Figure 3. Colomnar section of the basal Pennsylvanian and the Upper Mississippian. Here the complex Lower Mississippian strata is generally grouped into thePocono Group (Hickok and Moyer, 1940).

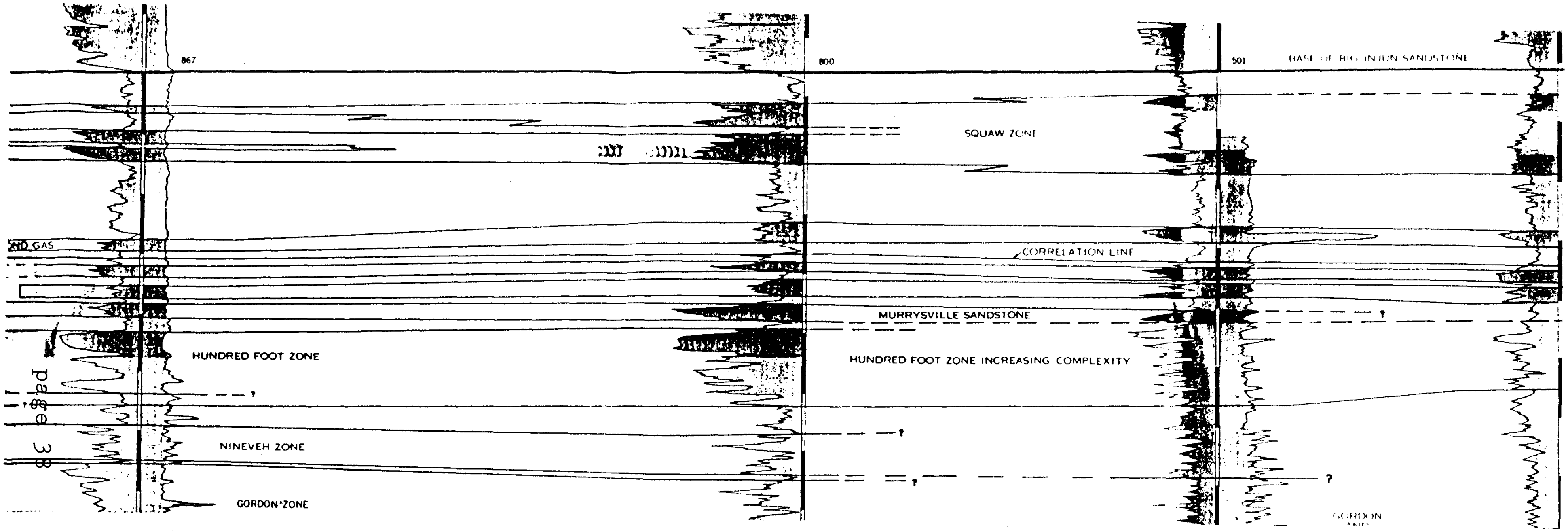


Figure 4. Cross section of the complex Lower Mississippian inferred from well logs. The line of the section goes through the area just south of the California Quadrangle (McGlade, 1967).

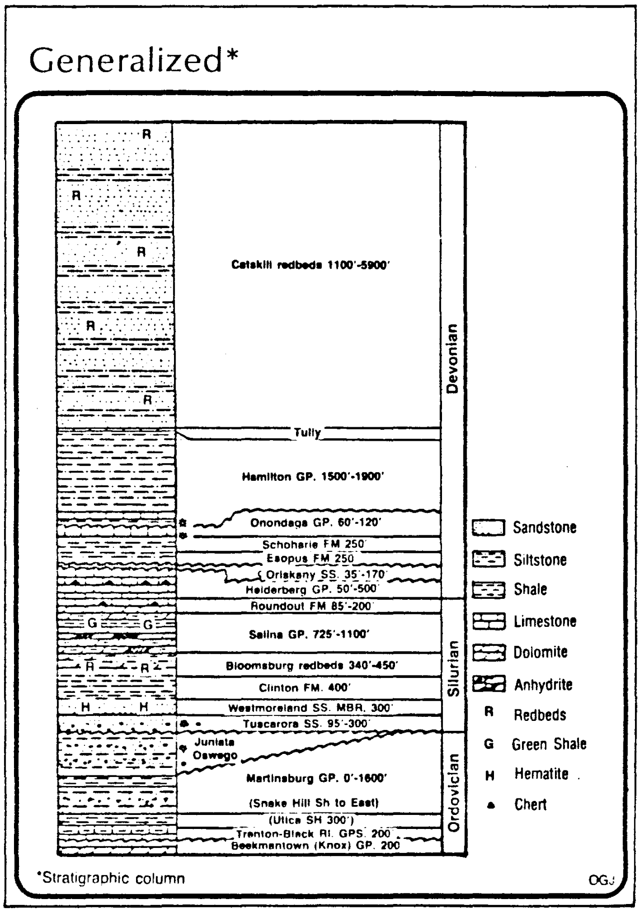


Figure 5. Simplified stratigraphic divisions used to describe the Upper Devonian (Timm, 1985).

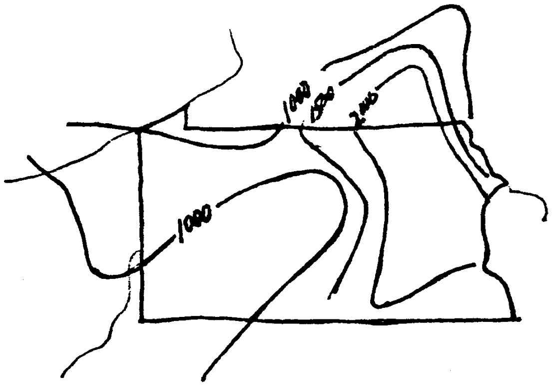


Figure 6. Upper Silurian isopach sketch map(Thomas,1955).

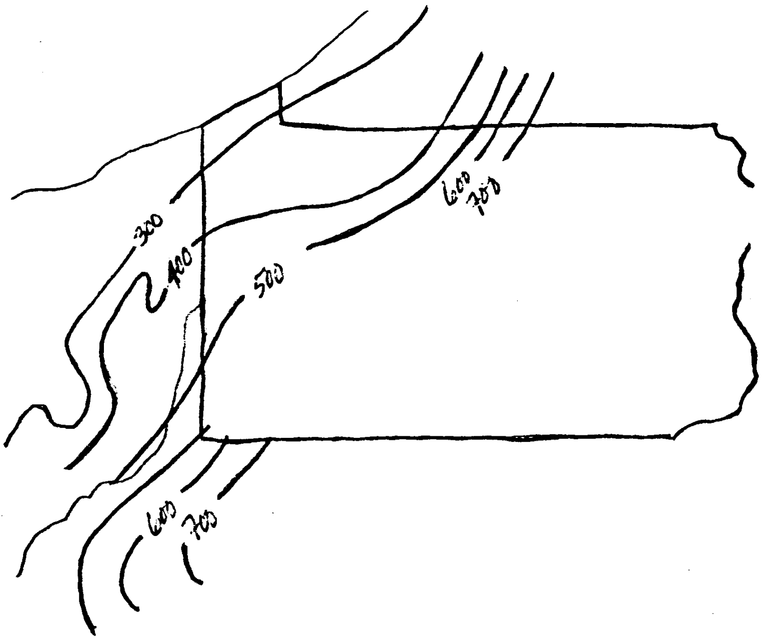


Figure 7. Isopach showing thickness between top of Queenston shale and base of Lockport dolomite of the upper and middle Silurian (Thomas, 1955).

Figure 8.Middle Ordovician Black River and Trenton isopach sketch map (Thomas, 1955).

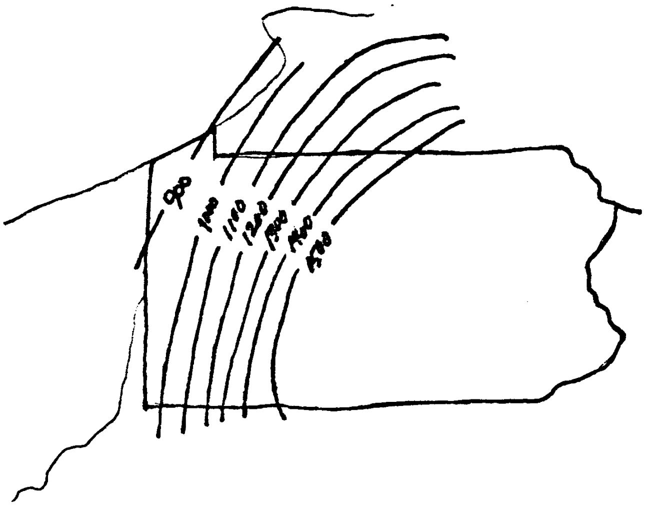


Figure 9.Upper Ordovician isopach sketch map (Thomas, 1955)

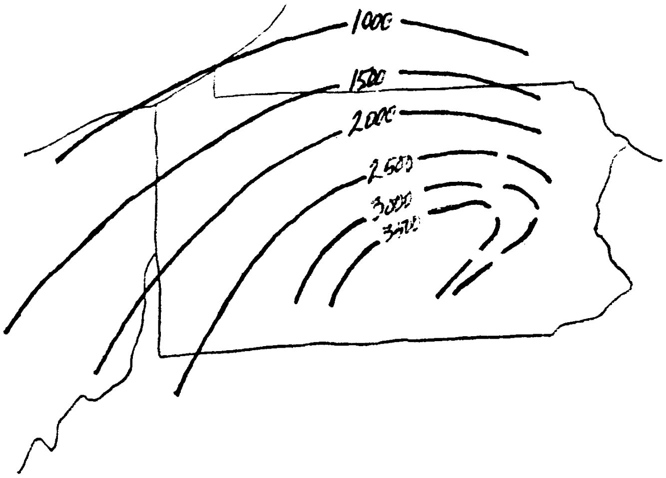


Figure 10. Middle and upper Cambrian isopachsketch map (Thomass, 1955).

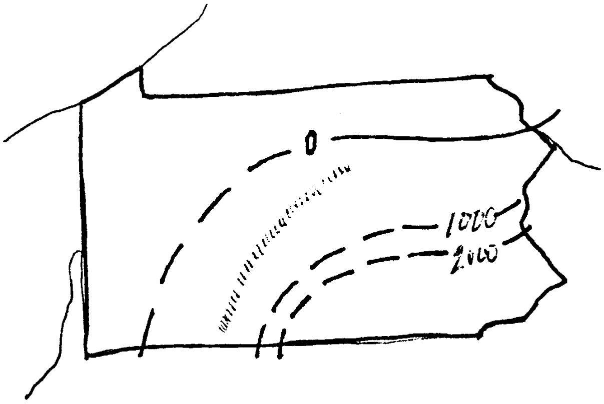


Figure 11. Lower Cambrian isopach sketch map (Thomas, 1955).

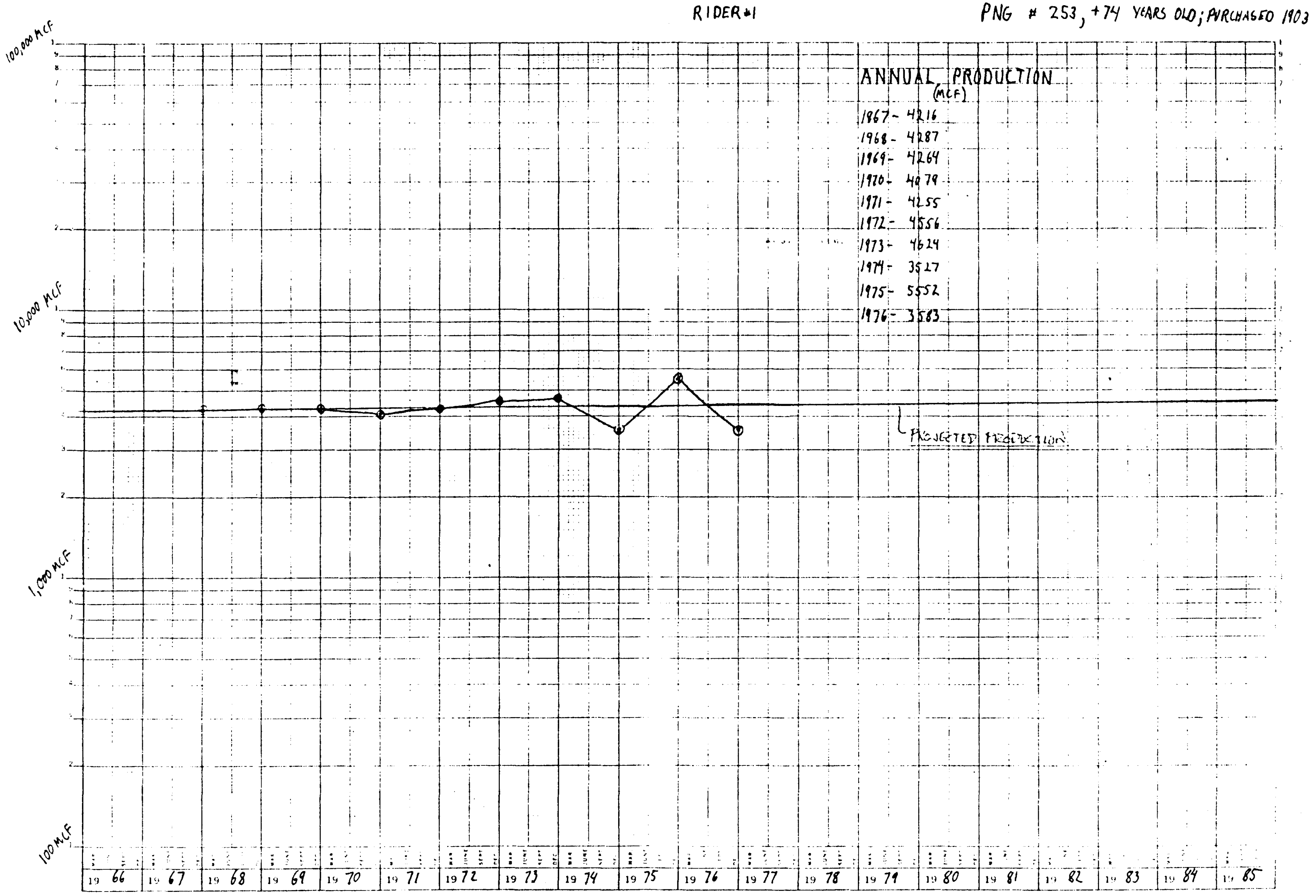


Figure 12. Graph showing the production of the Rider #1 in the northern portion of the California Quadrangle (Dean, 1977).

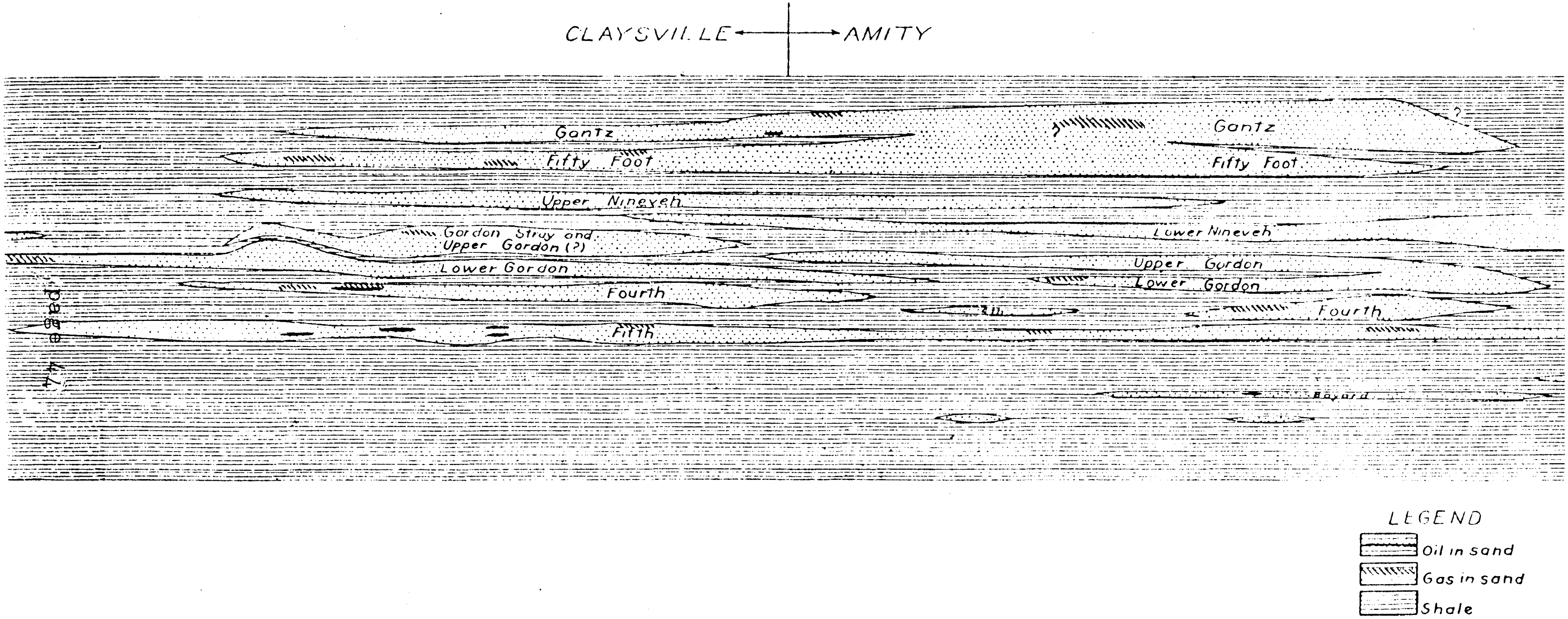


Figure 13. Generalized east to west cross section across southern Amity and Claysville Quadrangles showing the lenticular nature of the gas producing sands (Matteson and Busch, 1944).

AGE	ZONES	UNITS	SAND NAMES
MISSIS-SIPPIAN ?		Big Injun	Loyalhanna Big Injun-Mountain Burgoon
	MIDDLE AND LOWER POCONO		Shenango, Slippery Rock, Squaw Second Gas Berea, Cussewago, Corry, Knapp, Murrysville
UPPER DEVONIAN	RICEVILLE		Riceville Shale in north central Pennsylvania
	D UPPER SAND ZONE	D 3	Venango First, Hundred Foot, Fifty Foot, Gantz, Drake, Tuna Red Valley, Lytle, Rosenberry, White, Salamanca
		D 2	Venango Second, Salt, Upper Nineveh, Lower Nineveh, Snee, Shira, Boulder Venango Third Stray, Venango Third, Venango Fourth (Fourth), Venango Fifth (Fifth), Venango Sixth (Sixth), Grey, Black, Green, Gordon Stray, Gordon, McDonald Fourth, McDonald Fifth, Knox Third Stray, Knox Third, Knox Fourth, Knox Fifth, Wolf Creek, Clarion, Byram, Conewango, LeBoef, Magee Hollow
		D 1	Bayard Elizabeth
	C SHALE ZONE		
	B MIDDLE SAND ZONE	B 4	Warren First Warren Second Queen Glade, Bradford First, Eighty Foot, Clarendon Stray
		B 3	Clarendon, Sugar Run, Watsonville, Dew Drop, Chipmunk, Cherry Grove, Gartland, Upper Balltown, Lower Balltown, Speechley
		B 2	Tiona, Cooper Stray, Cooper Bradford Second Klondike, Harrisburg Run Deerlick, Sliverville
		B 1	Bradford Third Lewis Run Upper Kane Lower Kane Sartwell
	Bo LOWER SAND ZONE	Undivided	Haskill, Reily, Elk Humphrey, Benson, Alexander

Figure 14. Classification of the Upper Mississippian and Lower Devonian sands as suggested by Piotrowski (1980).

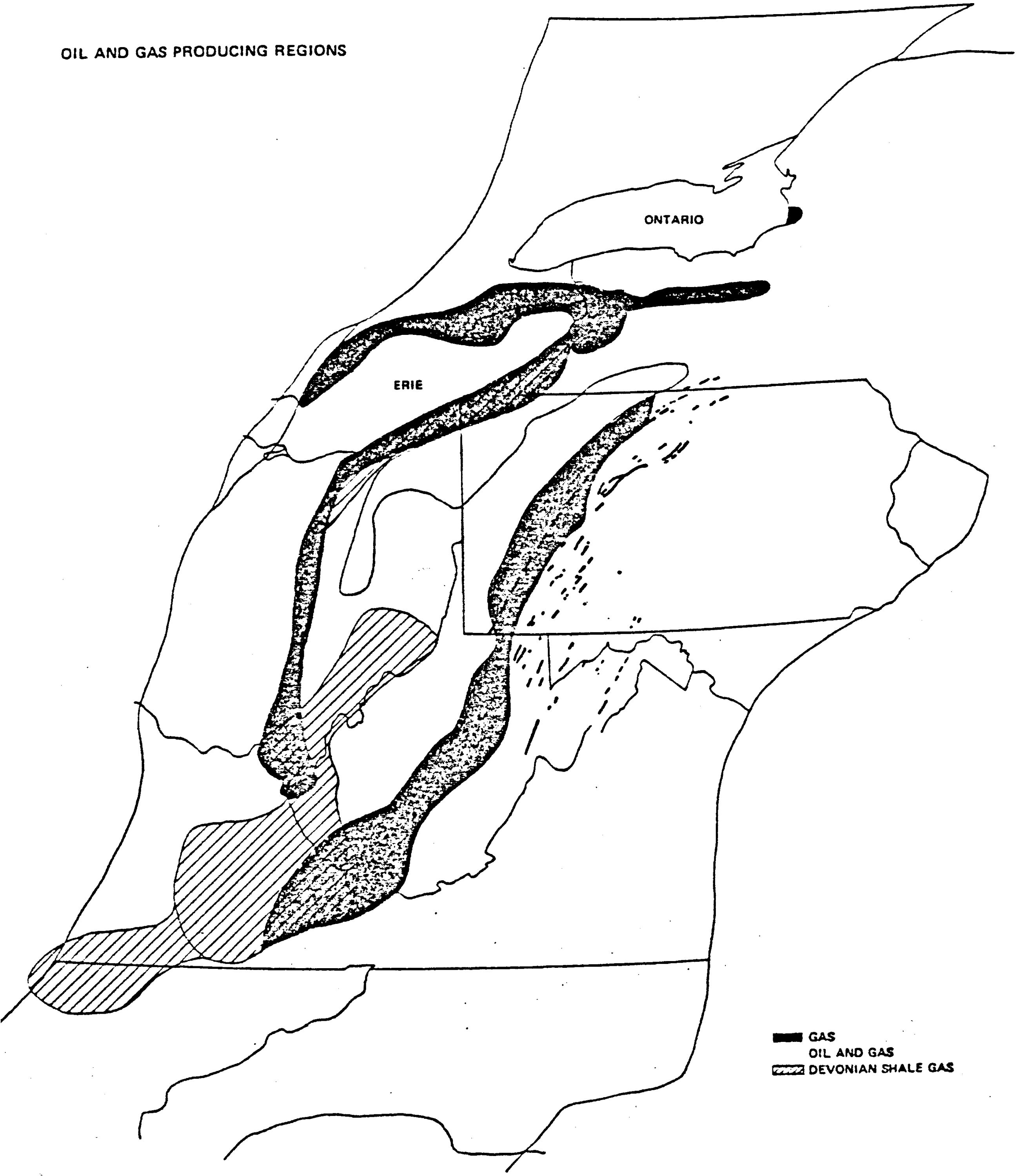


Figure 15. General diagram of the area where natural fracturing occured and effects oil and gas migration (Tillman, 1982).

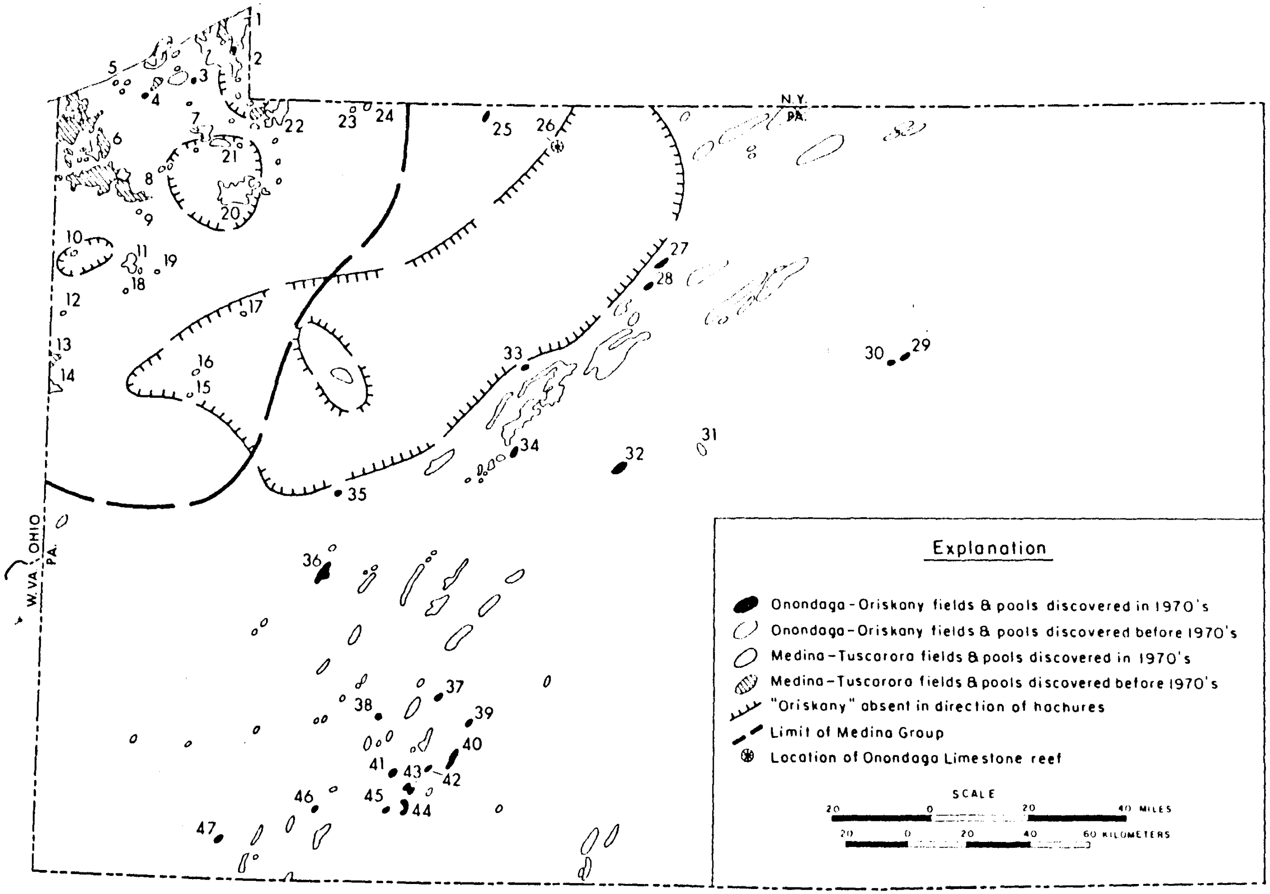
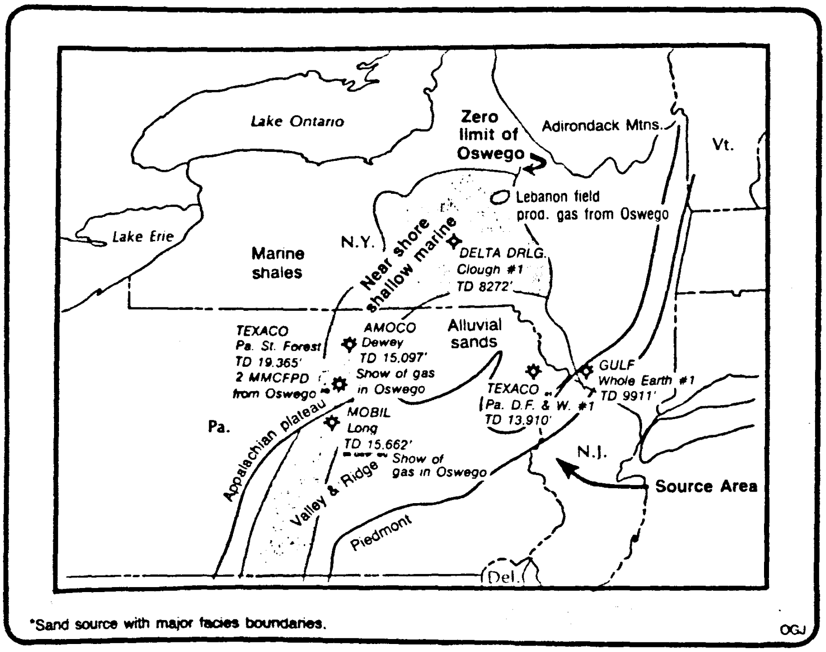


Figure 16. Diagram showing the location of Oriskany and Medina oil and gas fields in Pennsylvania (Harper, 1981).

Upper Ordovician*



*Sand source with major facies boundaries.

Figure 17. Diagram showing the near shore area of Ordovician strata which according to Henderson and Timm (1985) has good oil and gas producing potential.

IX. APPENDIX

MAPS

Plates 5-7 are maps complied using subsurface information collected from gamma and neutron logs. Thirty-two wells are actually spotted on the maps but in many cases the information on the logs was not usable. When the information was not usable NA was placed by the well location. In some areas the data was a little thin so contours had to be inferred. These are marked by dashed lines.

PLATE 5- Isopach from the top of the Big Injun to the base of the Bayard Sand showing sand content greater than 50%. Data for this map was collected from gamma ray logs. The maximum value shown on this map is 432 feet at the RSA #1. Near this well there is a large area which shows 390 feet of thickness or more. The lower set of contours also show a good area of 390 foot thickness. Areas of 400 foot thickness are shown around the Rider #1 and PNG 5040 wells.

PLATE 6- Isopach from the top of the Big Injun to the base of the Bayard Sand showing greater than 6% porosity. Data for this map was collected from density (neutron) logs. The general trends seen on plate 6 parallel those on plate 5. This is to be expected because sandstone does have a high porosity relative to the other rock types in the area. The amount of high porosity strata was commonly less than the amount of strata containing more than 50% sand. Maximum thicknesses range from 300 to 400 feet and tend to be located in the same general area as the maximum zones on the sand isopach.

PLATE 7- Data for this map was a little thin. A

consistent high density break on the neutron logs was used as recommended by Bruce Dean, Exploration Geologist at Pominex, Inc. In retrospect it probably would have been better to use the top of the Big Injun, which would have yielded more data points. The structural highs on this map are generally parallel to the maximum thicknesses seen on Plates 5 and 6.

Whether or not these maps could be used as a guide for successful drilling is hard to say. But the areas that should be considered are those which have the highest values on all three maps.

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