GEOLOGY

GENERAL

The geological information utilized builds upon the limited information contained in previously published geological reports. Many of these reports are over 75 years old during which time considerable mining activity has taken place. The mining operations may or may not confirm previous investigations. The geology of the watershed is complex and highly variable, however, the extensive field work required for identifying sources of acid mine drainage has provided some additional data on the geology of the watershed. It is felt that the geology as described in this report is adequate for the purposes of defining the subsurface conditions relative to the acid mine drainage problem.

The Toby Creek Watershed is underlain by up to 12,000 feet of sedimentary rocks dating back 540 million years to early Cambrian times. The region at that time was occupied by a ,vast inland sea. During this period of time, the present rocks were laid down as sediments. The, type of sediment varied with changing conditions so that a succession of shale,. limestone, sandstone, coal and clay, beds gradually accumulated and subsided. At sea level, extensive swamps developed in which large quantities of vegetable matter accumulated and gradually subsided. These deposits were covered with more sediments. This cycle continued for many eras and has resulted in the rocks presently exposed in the watershed.

Some 200 million years ago, a tremendous. uplift of the earth's crust occurred from Alabama to New York. The forces were directed from the southeast and lifted the accumulated sediments above sea level. The sediments were severely folded in eastern Pennsylvania, but gentle folding occurred in the western part of the state. This area has since been above sea level and subject to the erosional processes of weathering and stream action.

Immediately following the uplift, erosional forces reduced the area surrounding the watershed to a region of broad hills and valleys. This surface is known as a peneplane. The remnants of such a condition exist to this day in that the hilltops in the area are nearly at the same level or elevation.

Due to a gradual uplift of the region, the streams have undergone a minor rejuvenation. This has increased the gradient of the stream and subsequently increased their ability to erode the underlying strata. The results of this rejuvenation were the steepening of the stream valleys with an associated lengthening, of the streams to their present state.

The topography of the Toby Creek Watershed is characterized by steep, rugged valleys and broad, flat hilltops. The lower valley of Toby Creek near the mouth is steep sided and narrow while the upper reaches are broader and wider. The steepness, near the lower end is apparently due to the outcropping of the rocks from the Mississipian period and the Pottsville Formation of the Pennsylvanian Period. These rocks are predominantly massive sandstone and are more resistant to weathering and erosion processes. The broad, hilltop cap rocks of the watershed consist of shale, sandstone,' coal, and clay of the Allegheny Formation.

The gradient of Toby Creek averages 32 feet per mile with a slightly steepening gradient approaching the stream mouth. This relatively steep gradient and resulting high velocity of the stream prevents the accumulation of the iron precipitates (yellow boy, etc.) in the stream bed; instead as the stream enters the tranquil backwaters of Piney Dam, the reduction in velocity permits the accumulation of these compounds at this location.

The drainage system of Toby Creek is dendritic in nature. This affect resembles the branching of a deciduous tree. This is due to the underlying bed rock (sandstones of Pottsville Formation) which is uniform in its resistance to erosion and has no control over the direction of valley development or drainage.

REGIONAL STRATIGRAPHY

The exposed rocks of the Toby Creek Watershed are sedimentary in nature and belong to the Mississippian and Pennsylvania series of the Carboniferous system. The deeper stream valleys contain recent alluvium deposited during the Quarter nary Period. The exposed rocks are underlain by a great thickness of sedimentary rocks. Information of these rocks has been gathered solely from a study of bore hole records of oil and gas wells. The rocks penetrated by these wells are believed to be portions of the Portage, Chemung and Catskill Formation of the Devonian system and a part of the Mississippian series of the Carboniferous system. A discussion of the exposed strata of the Toby Creek Watershed follows.

PENNSYLVANIAN SYSTEM

The Pennsylvanian system contains the principal coal bearing formations of the State. The rocks range in age from 270 to 325 million years old. They make up virtually the entire surface exposure of the Toby Creek Watershed. Deposited in near shore marine or continental environments in the northcentral part of the Appalachian basin; these rocks consist of interbedded shale, sandstone, siltstone, limestone, clay and coal beds. (See generalized stratigraphic column, page 19.) The system has been subdivided into four groups,. named from the youngest to the oldest: Monongahela, Conemaugh, Allegheny, and Pottsville. The Monongahela, Conemaugh groups and the upper portion of the Allegheny group have been eroded. or represent a hiatus in the Toby Creek Watershed. A discussion of the remaining portion of the Allegheny and Pottsville groups follows.

ALLEGHENY GROUP

The Allegheny group includes all rock between the top of the Upper Freeport coal seam to the base of the clay beneath the Brookville coal. It is composed of sandstones and shales, interbedded with minor amounts (volumetrically) of coal, clay, and limestone. The Allegheny group has divided into three formations: Freeport, Kittanning and Clarion. The Freeport formation and the upper portion of the Kittanning formation are not present in the. watershed. The portion of the Allegheny group present in the watershed attains a maximum thickness of 160 feet.

KITTANNING FORMATION .

The Kittanning formation extends from the top of the Upper Kittanning coal seam to the base of the clay under the Lower Kittanning coal. In the Toby Creek Watershed, only the shale above the Lower Kittanning coal is present and that being in isolated hilltops. The Lower Kittanning coal ranges from 3 to 4 feet in thickness and is considered to be, in terms of quality, the most valuable seam of coal in the Watershed. Great quantities of coal, however, have been removed by erosion and the remaining reserves have essentially been mined out. The seam reached its greatest development between Miola and Helen Furnace in the eastern perimeter of the watershed where its was strip mined. Varying qualities of plastic and flint clay underlie the coal seam with thicknesses ranging from 3 to 8 feet.

CLARION FORMATION

The Clarion formation extends from the. base of the Kittanning Formation to the base of the Brookville underclay. This formation contains nearly all of the mineable coals in the watershed. It consists of interbedded sandstone, siltstone,shale, clay, coal, and limestone. The principal, mineral resources of the formation, in descending order, include: Vanport limestone, Upper Clarion coal, Lower Clarion coal, and the Brookville coal.

The interval between the Lower Kittanning clay and the Vanport limestone generally consists of coarse grained sandstone-occasionally interbedded with shale or siltstone. The Vanport limestone, a persistent bed in western Pennsylvania, has been rarely observed in the Toby Creek Watershed. It is believed to have only spotty occurrence and has attained a thickness at most of eight feet. Immediately above the limestone is a layer of iron ore several inches in thickness. An iron furnace at Helen Furnace utilized the iron ore and limestone from this member. In a large area of the watershed where the Vanport limestone is absent, the interval between the Lower Kittanning and Clarion coals is occupied by a massive coarse grained sandstone and dark shale.

The absence of the Vanport limestone has major implications relative to the acid mine drainage conditions in the watershed. Groundwater quality in the acquifers normally associated with the Vanport limestone is of a highly alkaline nature. Intermixing of. these waters (when present) with acid mine drainage neutralizes the acidity of the water and, in essence; acts as a buffering agent. Since the Toby Creek Watershed contains very little limestone, natural renovation of acid mine drainage is virtually non-existent. Without this renovation, it is not known whether the streams within the watershed can ever become totally non-acidic.

The Clarion coals have both been extensively mined in the watershed. Neither of the coals are entirely persistent, with one or the other frequently missing. Thus, seam identification has been difficult. Both Clarion coals are sulfurous, carry one or more binders and contain high ash contents. The Upper Clarion coal varies in thickness from 6 to 36 inches. This is separated by the Lower Clarion coal by approximately 20 feet of shale. The Lower Clarion ranges from 18 to 42 inches in thickness. Both seams are underlain by plastic clay, 3 to 10 feet in thickness. The coals have been extensively deep mined on the western watershed perimeter between Lucinda and Arthurs. Strip mines have removed the coals on the broad hilltops anywhere high enough to hold the coal and where little overburden was encountered. A considerable quantity of the mineable Clarion coals has been exhausted in the watershed.

The interval between the Lower Clarion coal and the Brookville coal is separated by up to 70 feet of shale with occasional interbeds of sandstone. The Brookville coal seam averages 4% feet in thickness and is locally 7 feet thick. It has a high sulphur and ash content and contains thick partings of shale and pyrite. It is underlain by up to-10 feet of variable quality clay. Relatively little mining has been done on the Brookville coal due, in part, to the poor quality of the coal and the high level of activity on the Clarion coals; however,

GENERALIZED STRATIGRAPHIC COLUMN OF EXPOSED ROCKS
TOBY CREEK WATERSHED
SL 191

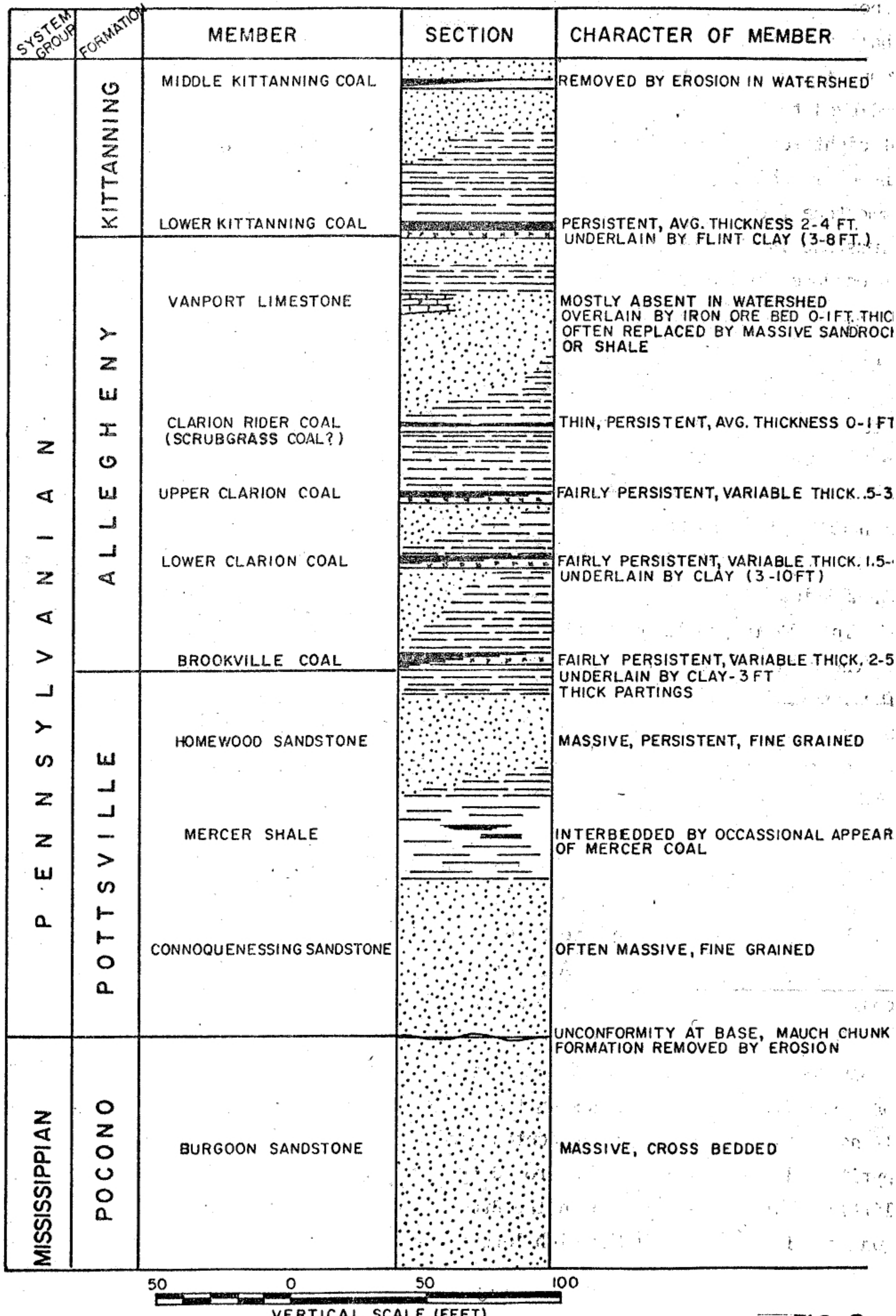

FIG. 2

there are probably large, unproven reserves of Brookville coal remaining in the watershed and, therefore, some potential exists for future development.

POTTTSVILLE GROUP

The Pottsville group extends from the bottom of the Brookville underclay to the base of the Connoquenessing sandstone. It consists of thick bedded resistant sandstones with thin lenses of shale and coal. It attains a maximum thickness of 130 feet in the watershed. The rocks of the Pottsville group form the hillsides and valleys of the watershed area. It consists of the following formations in descending order: Homewood, Mercer and Connoquenessing. The upper limit of the group is occasionally separated from the Brookville coal by a, variable thickness of shale. The lower limit lies unconformably on the Burgoon sandstone of the Mississippian period since the Mauch Chunk formation has been eroded from this area. The line of separation is not clear due to the fact that the sandstones of the Pottsville and Burgoon Sandstones are very similar in nature.

Homewood Formation

The Homewood formation varies in thickness from 30 to 40 feet. It extends from 'the bottom of the Brookville underclay to the top of the Mercer shale. It consists of a gray massive coarse-grained sandstone.

Mercer Formation

The Mercer shale formation varies in thickness from 6 to 40 feet. The formation consists primarily of black and brown shales interbedded with thin beds of coal and clay. The Mercer coal bed sporadically outcrops in the watershed stream valleys but little, if any, coal has been mined.

Connoquenessing Formation

The Connoquenessing formation ranges from 30 to 50 feet in thickness. It extends from the base of the Mercer shale to the Mississippian-Pennsylvanian contact. It consists of a coarse-grained, massive sandstone with occasional inter-beds of shale.

MISSISSIPPIAN SYSTEM

The only exposure of the Mississippian system consists of the Burgoon sandstone of the Pocono group. It outcrops along the steep hillsides near the mouth of Toby Creek and is the oldest rock exposure in the watershed. The contact with the Pottsville group could not be ascertained in the field due to the heavy talus on the valley walls.

The Burgoon sandstone attains an average thickness of 310 feet in the watershed. It is of non-marine origin and is usually, thin bedded and unclean. It also contains frequent interbeds of thin shale lenses.

STRUCTURAL GEOLOGY

The Toby Creek Watershed is located on the northern limits of the Appalachian coal basin. The basin or synclorium is a large northeast-southwest trending downfold of strata. It is a near flat lying strata which is only occasionally broken by small faults and low, broad folds.

Limited information regarding structure has been obtained in and around the area of the Toby Creek Watershed. The geology of Clarion County was investigated by the Second Geological Survey of Pennsylvania (H.M. Chance) in 1880. In 1911, the United States Geological Survey (Shaw and Mum) published the geology of the Foxburg and Clarion quadrangles, including a small portion of the Toby Creek Watershed. Chance, in the 1880 study, reported straight, parallel folds bounding the east and west boundary of the watershed; the Bradys Bend syncline and the Millersville anticline, respectively. In 1911, however, Shaw and Munn could find no such evidence of these folds, though the study proceeded only as far as Tarkiln Run of Toby Creek.

In lieu of complete geological data, structure contours hate been formulated for the Toby Creek-Watershed. Since the area has been heavily surface mined the topography of such activities are found on the U.S.G.S. 7 1/2 -minute quadrangle series. Coal elevations hate been ascertained from these sites and correlated with available drill hole and deep mine data. Structure contours hate been compiled on the Lower Clarion coal seam. The bed is considered to be the most persistent and heavily mined of any in the watershed. Therefore, the seam, where mined out, would be capable of generating more data relative to structure determinations. The resultant structure contours are in intervals of 20 feet. It is felt that the contours are accurate to 10 feet. It must be emphasized that the structure obtained is of a regional nature only. Localized conditions at a certain mine site will vary with the formation presented. For the purpose of this report, however, it is felt, that the structure presented reveals the regional trends and patterns.

As a result of the determination, it can be seen that the structure can best be described over most of the watershed as a monocline rising gently, less than one-half degree, to the northwest. As the structure is followed to the south, beginnings of the organized fold, familiar to the southern portions of the basin, begin to appear. The results of these gentle folds can be seen in the slightly steepening dip and change in strike direction in the vicinity of the mouth of Toby. Creek. When the southerly dip is combined with the nearly constant elevation of the hill tops, the reason for the presence of the Kittanning Formation in the southern reaches of the watershed become evident. Similarly, the Lower Clarion coal bed raises an estimated 190 feet from the mouth to the headwaters of Toby Creek. As a result of this rise, the isolated patches of coal near Crown represent some of the northernmost reaches of mineable bituminous coal in the Appalachian basin.

The direction of groundwater flow seems to be largely controlled by the general structure of the area. Most springs were seen to exit primarily on the southeast sides of the hills. Exceptions to this were some flows monitored along Step Creek and Toby Creek from Helen Furnace and Cooks Corners. This may be due to local anomalies in structure in these areas. The interrelationships between abandoned surface mines and-groundwater contamination is discussed under the Exploratory Drilling Program, page 25.

GEOLOGIC FACTORS AFFECTING ACID MINE DRAINAGE ACID PRODUCTION

The nature and quantity of acid mine drainage produced as an aftermath of coal mining is determined by various hydrologic and geologic factors. Some of these factors are:

1. Thickness and composition. of the coal seams and associated strata
2. Depositional environments of the strata.
3. Size and chemical constituents of the pyrite in the coal and associated strata.
4. Folding, fracturing, joints, faults, and strike and dip of the strata.
5. Location and extent of mined out area.
6. Roof thickness and character.
7. Topography.
8. Position of water tables
9. Permeability and porosity of strata.
10. Availability of carbonates for natural renovation.

The basic theory of acid mine drainage formation is simple and well known. Coal mining exposes the sulphur-bearing minerals, pyrite and marcasite, to air and water. These minerals are oxidized chemically and biochemically, producing sulfuric acid., ferrous and ferric sulfate, and other acid salts such as the sulfates of iron, aluminum, and manganese. The mine drainage may also contain the neutral sulfates of calcium and magnesium when calcarious rocks are present.

Recent research conducted by Williams (1960), Williams and Ferm (1960), Williams and Keith (1963), Caruccio (1968, 1970, 1972), and Caruccio and Ferm (1974), has begun to develop patterns in acid mine drainage formation in Western Pennsylvania. Through the use of fossils, Williams first determined the stratigraphic paleoenvironments of deposition and -their lateral variations for. each of the major coal seams in the Allegheny Group. He found that in the basal portion of the Allegheny Group, the rocks contain fossils indicative of a marine-brackish water paleoenvironment. In the upper portion of the Group, fossils are present which indicate a continental freshwater paleoenvironment. In general, as one passes upward through the stratigraphic succession, the rocks grade slowly from marine to continental, indicating a slow marine regression over a long period of time. This work was further refined by Williams and Ferm (1960), who demonstrated that the basal brackish rocks in the Allegheny Group also vary laterally, becoming progressively more marine to the west.

The significance of this, to the understanding of acid mine drainage, was revealed in a study by Williams and Keith (1963). This study investigated the possible correlation between sulphur (primarily as pyrite) in coals and the paleoenvironment of deposition of the coals. It was found that the amount of sulphur in the Lower Kittanning coal seam increased westward, directly correlating with the westward transition from continental to marine paleoenvironment. This was inferred to hold true for the other coal seams of the Allegheny Group.

For the past eight years, Caruccio has been investigating the nature of the pyrite which causes the acid mine drainage problem. In a series of field and laboratory studies conducted in western Pennsylvania, he determined that the most significant parameters affecting acid formation are:

1. Mode of occurrence of the pyrite.
2. Distribution of certain trace elements in the pyrite.
3. Permeability of the host rock, as a contributing factor to the oxidation rate.
4. Availability of calcium carbonate for natural renovation.
5. Groundwater pH before mining, as a control on the iron bacteria which catalyze the acid producing chemical reaction.

The studies showed that there are four types of pyrite occurrences in coal strata

1. Euhedral crystals less than 10 microns in diameter.
2. Coarse-grained masses replacing original plant matter, greater than 25 microns in diameter.
3. Coarse-grained platey masses occupying joints in the strata, greater than 25 microns in diameter.
4. Fine grained framboidal pyrite, generally occurring as spherical clusters of 0.25 micron particles.

The fine-grained framboidal and euhedral pyrite appear to have been formed contemporaneously with the host strata, since the pyrite grains are aligned parallel with bedding and form an integral part of the structure. These types of pyrite are products of the paleoenvironments of deposition for the strata. The other types of pyrite are secondary forms, resulting from deposition in joints and replacement of plant material.

Caruccio has further determined that only the frambcidal primary pyrite is signficantly reactive. Samples containing similar amounts of total pyrite, but only a small percentage of framboidal, produce significantly less acid than samples with a high percentage of framboidal pyrite.

The reasons for the reactivity of framboidal pyrite appear to be at least partially controlled by the existence of trace elements. Size alone is not the answer, since coarse-grained pyrite was mechanically ground to a size equivalent to framboidal pyrite and tested, without a significant increase in acid production. Spectroanalysis of samples by Caruccio has shown significantly more titanium in stable pyrite than in reactive pyrite, and presence of silver in reactive samples only. More research is being conducted to determine if silver increases oxidation tendency, or if titanium increases stability.

Recent work by Caruccio and Ferm (1974), and work in progress, has determined the framboidal pyrite to be associated with strata from back barrier and lower delta plain deposits. Criteria are being developed to recognize paleoenvironments in the field, in hopes that progress can be made toward mapping these environments in the Appalachian coal fields.

There are several implications of these studies for the Toby Creek Watershed. The. surface rocks of the watershed are from the basal portion of the Allegheny Group, representing restricted near-shore marine and marine paleoenvironments. As such, the Clarion coals and associated strata contain the greatest amounts of framboidal pyrite, and are therefore the worst acid producers.

The situation within the watershed is worsened by the scarcity of Vanport limestone, which is a major contributor to natural renovation throughout much of western Pennsylvania. The lack of limestone, high degree of reactive pyrite, and poor reclamation practices of past mining, have combined to produce the serious acid mine drainage problem in the Toby Creek Watershed. Moreover, the low pH values in many areas probably encourage the growth of various iron bacteria, which act as a catalyst in the acid production process.

EXPLORATORY DRILLING PROGRAM

Introduction

During the early stages of the study, one of the most persistent problems in relating geology to the acid mine drainage problem was tracing the movement of the pollution. Normally, seepages from. surface mined land would occur at the toe of spoil and migrate in accordance with the geologic structure. At other times, rainfall would fall onto surface mined land, (particularly hilltop mines) and disappear into the subsurface. In conjunction with this problem, springs and wells located far downslope of these mining areas, were discharging considerable quantities of acid mine drainage. The quality of the water closely resembled the drainage that normally would be discharged as seepage or runoff from strip mines.

It was suspected that precipitation was falling on the hilltop surface mines and infiltrating the highly permeable and acidic Clarion spoil material. This was thought to be a logical assumption in that the surfaces of the mines lacked vegetation, were flat lying, and contained rocky and pyritic overburden. The flow was then assumed to infiltrate to an aquifer and then. conveyed to the surface, exiting in the form of springs and wells. To verify this assumption, an exploratory drilling project, SL 191-0-101.5, was established for various areas in the Toby Creek and adjoining Deer Creek (SL 193) Watershed. Core holes were drilled between the abandoned mine sites and the pollution points. The cores were examined in the field and in the office. Holes were drilled to depths so as to verify the presence or absence of a single contaminating transmission zone.

The drill logs and related drawings of the project are presented in the Appendix and should be referred to in conjunction with the following discussion.

Toby Creek Area No. 1

The project area was located near the mouth of Toby Creek on State Game Lands No. 72. The purpose of the project was to determine the pollution source to the spring monitored by weir number TY-147. It was suspected that the possible recharge area was a large hilltop strip mine in the Clarion coal seam approximately 400 feet above the spring. Holes were drilled just above the spring to depths of 60 to 100 feet on township road T-576. Two additional holes were drilled adjacent to the strip mine at depths ranging from 325 to 420 feet on L.R. 16054. The stratigraphy of drill hole No. 6 was determined by gamma ray logging performed by the U.S.G.S. The farthest advance of the holes were into the Burgoon sandstone of the Mississippian period.

An examination of the core borings revealed that an iron precipitate, believed to be ferric hydroxide had formed on the rocks near the surface of each hole. An analysis of the deeper holes near the strip mine (D.H. 5 and 6) found no evidence of iron precipitate in any deep zone and thus ruled out the contamination of a single acquifer zone. Therefore, it would appear that the pollution is following a near surface or soil-rock. interface path. The recharge to the polluting spring is believed to be precipitation infiltrating the highly acid spoil of the strip mine and flowing along a near surface path to the spring. Specific recommendations for this area are presented in Project Area No. 1 of the proposed abatement plan.

Toby Creek Area No. '2

The project area was located approximately 1 mile south of Lucinda. The purpose of the project was to determine the source of pollution to the well (TY-75). Bore holes were. drilled below a small hilltop strip mine in the Clarion seam on T-613 and a private driveway. The holes were drilled to depths ranging from 30 to 110 feet. The holes extended into the Connoquenessing member of the Pottsville formation.

An examination of the core borings reveals a limited amount of iron precipitate had formed on the rocks near the surface of each hole.

The water carrying the precipitate would appear to follow a near surface path and probably originate from the strip mine on the adjacent hill. No evidence of a single contaminated acquifer zone. could be found in the core borings; however, it is improbable that the mine is contributing significant amounts of pollutants to the gas well monitored by TY-75. An inspection of the water quality discharged from the well reveals very large quantities of acidity, iron, and sulphates. It is highly unlikely that the small hilltop mine is capable of producing consistent amounts of mineralization to the degree observed at the well. Recommendations for this area are presented in Project Area No. 6 of the proposed abatement plan.

General Conclusions

As a result of the drilling program, it appears probable that abandoned surface mines topographically situated on hilltops are capable of discharging variable amounts of acid mine drainage to shallow groundwater systems. It is felt that rainfall is percolating through an acidic, permeable spoil until it is contained by an impervious surface (usually the bottom of a strip mine pit.) The flow is then conveyed laterally in accordance with local geologic structure to a point where it intercepts the soil mantle. The flow then follows a near surface flow path until it appears to exit downs lope at the surface usually at a spring. The quantity of pollution appears to depend on the' surface area of

the site, the degree of vegetation present, the amount of acid producing material in the spoil, the permeability of the surface material, the type and amount of backfilling afforded to the site and the presence of drainage facilities. The presence of a single contaminated acquifer zone was not found to exist as a result of this program.

The pollution attributed to gas wells is seen as a more complex problem. At certain extreme instances, the pollution to these wells may have its source from abandoned surface mines. It seems more likely, however, that the problems are generated far below the ground surface and beyond the influence of the local surface mined areas. An in depth study of the gas well pollution problem requires the use of more sophisticated hydrogeological techniques.

General Recommendations

The general findings of the exploratory drilling program should not be applied in a specific manner to all seepages and springs seemingly far removed from mined areas. The geology of the watershed relative to groundwater hydrology is far too complex to put into simplified terms. Some general recommendations, however, can be made that should improve the acid mine drainage conditions in these areas.

Relying on the assumption that the surface mining of coal within the watershed has affectively disrupted the groundwater system to some degree, it would seem logical that reclamation of these sites is in order. It is felt that regrading the sites and installing drainage facilities to promote the rapid expedition of runoff is essential. Special compaction of the surface to prevent the wholesale percolation of water into the spoil may be necessary in some cases. The experimental program at a strip mine in the watershed is testing several methods to achieve this end. Also considered necessary is complete revegetation of the reclaimed site. The root system of the vegetation will help to absorb the water that would normally be infiltrating through the acidic spoil.

Gas well plugging is considered a viable means of abating deleterious flows. This technique has been used in the adjacent Deer Creek Watershed (SL-193) and has met with limited success.

If these measures are implemented, there is no guarantee that the acid mine drainage discharged from isolated springs and wells will be completely abated. It is felt that many of the sources have been discharging naturally for a period of many years. The abatement of these sources would be considered next to impossible. An evaluation of, adjacent watersheds in the area indicate similar conditions of groundwater contamination. The problem may be one of a regionalized nature and not one due solely to local conditions. It is felt, however, that the quantity of water being discharged from these sources will be reduced if the abatement measures are implemented over a basin-wide area.