INTERACTION OF HYDROLOGIC AND MINING VARIABLES IN THE WESTERN PHOSPHATE FIELD, U.S.A.

Dale R. Ralston

Professor of Hydrogeology
College of Mines and Earth Resources
University of Idaho
Moscow, Idaho 83843

ABSTRACT

The early identification of potential water resource problems in a mining district is necessary for efficient mineral resource development balanced with environmental management. The Western Phosphate Field, most of which is located in Idaho in the Pacific northwest region of the United States, provides an opportunity for effective conflict identification and for problem resolution in the early stages of mining development.

Water resources within the Western Phosphate Field exist in complex ground water and surface systems. However, an areally consistent pattern of hydrogeologic properties within individual units of the "Phosphate Sequence" (Dinwoody, Phosphoria and Wells formations) allows regional analysis of ground water flow systems. Six existing open pit mines were analyzed to characterize site specific ground water flow patterns. Two factors were found to be most important in controlling ground water systems at the sites: (1) the type of geologic section at the mine, i.e. whether the sedimentary units dip with the slope or into the slope and (2) the topographic location of the mine with respect to ridge valley systems. Most of the mines are in the recharge portion of flow systems and are thus free of major dewatering problems.

INTRODUCTION

The early identification of potential water resource problems in a mining district is necessary for efficient mineral resource development balanced with environmental management. The Western Phosphate Field, most of which is located in Idaho in the Pacific northwest region of the United States, offers an opportunity for effective conflict identification and for problem resoulution in the early stages of mining development.

The Idaho phosphate deposits contain about 80 percent of the ore reserves of the Western Phosphate Field, or about 35 percent of the United States reserves [1]. Phosphate ore is mined by open-pit methods along outcrops of the Meade Peak Member of the Phosphoria Formation, where it has been exposed through folding, faulting, and erosion (Figure 1).

Water resources within the phosphate field exist in complex ground water and surface water flow systems. These complex water resource systems have developed over geologic time, through the interaction of many environmental factors. The geologic, topographic, hydrogeologic, chemical, and climatic characteristics of the area influence the occurrence, movement, and quality of the water resource systems.

Mining activities within the phosphate field necessarily alter the existing environmental characteristics and therefore impact the water resource systems. The water resource systems also have the potential to hamper mining operations in certain areas through pit flooding and through pit and waste dump stability problems.

An expected future increase in mining activities increases the potential for impacts on the water resource systems. It is evident that a thorough understanding of the many interrelated factors which control the water resource systems is necessary before potential mining impacts can be predicted and assessed. A definite need exists for a systematic method of identifying water resource systems at mine sites and evaluating mine sites for potential hydrologic impacts. Accurate identification of water resource systems allows more efficient environmental management with less cost to industry. It also provides important inputs for mine management.

The purpose of this paper is to demonstrate the usefulness of understanding regional hydrogeologic characteristics in assessing water resource impacts on and from development of a new mine. Knowledge of the regional hydrostratigraphic characteristics allows pre-mining prediction of water resource systems and guides hydrologic data collection during mine construction. The local ground water conditions at a mine site are best understood in the light of the regional conditions.

This paper presents a regional description of ground water flow systems in the Western Phosphate Field and then describes the local conditions at six mine sites.

HYDROGEOLOGIC SETTING

Most of the Western Phosphate Field is located in an area dominated by a northwest-southeast trending system of ridges and valleys. The ridges vary in length from 8 to 64 km and in width from 2 to 16 km. The ridges range in elevations from 2000 to 3000 m. The valleys are generally narrower and shorter and range in elevation from 1700 to 2300 m. The average annual precipitation in the area ranges from 38 to 89 cm with roughly half in the form of snow. Snow accumulations on the lee (northeast) side of the ridges may exceed 9 m [2].

Rocks exposed in the area range in age from Precambrian to recent; however, the marine sedimentary rocks of Carboniferous, Permian and Triassic age are of primary importance to the phosphate mining industry. Phosphate ore is mined from the Meade Peak Member of the Phosphoria Formation, which is of Permian age.

The geology of the study area is extremely complex. The general northwest-southeast trend of the ridges and valleys can be attributed to major thrusting and deformation during the Laramide Orogeny of Cretaceous age. Structure of the area is dominated by major northwest-southeast trending synclines, anticlines, and associated faults. Subsequent erosion formed many valleys along the anticlinal fold axes. Normal faulting of the region during late Tertiary and throughout the Quaternary further complicates the structure. Quaternary basalts blanket a portion of the area. Most valleys of the area contain Quaternary deposits of colluvium and alluvium.

The sedimentary sequence of the Dinwoody, Phosphoria, and Wells formations forms the basic stratigraphy at all mine sites within the Western Phosphate Field. Colluvium and alluvium are also important at some sites [2].

The Dinwoody Formation of Triassic age consists of an upper member and a lower member. Each member is about 300 m thick and consists of interbedded limestones, siltstones and shales. Hydrogeologic investigations suggest that both members of the Dinwoody Formation will support ground water flow systems throughout the mining area, provided that recharge is available to the formation. Springs issue from the lower member of the Dinwoody Formation at most mine sites.

The Phosphoria Formation of Permian age consists of the Rex Chert Member and the Meade Peak Phosphatic Shale Member. The Rex Chert Member is about 60 m thick and consists primarily of chert and mudstone. The Meade Peak Member is 30 to 60 m thick and consists primarily of mudstone and phosphorite. Phosphate is mined from high grade zones in the Meade Peak Member. The Rex Chert and Meade Peak members of the Phosphoria Formation do not support any major ground water flow systems in the area. This conclusion is based on the limited number and size of springs that discharge from the Phosphoria Formation and from detailed data from several mine sites. The Phosphoria Formation appears to separate the flow systems in the Dinwoody Formation from deeper flow systems in the Wells Formation.

The Wells Formation of Pennsylvanian age is divided into an upper member and a lower member. The upper member is 300 to 400 m thick, and consists of a sandstone with some limestone and dolomite. The lower member is 200 to 300 m thick and consists mostly of limestone. Both members of the Wells Formation support major ground water flow systems in the Western Phosphate Field. A number of streams originate in the Triassic Dinwoody Formation, flow across the Phosphoria Formation and are lost in the upper member of the Wells Formation. Several large springs in the area discharge from the Wells Formation.

Structural features have greatly influenced the development of ground water and surface water flow systems in the area. Major surface drainages are generally parallel to fold axes or follow fault structures. Stream valleys generally occur within the eroded cores of anticlines and ridges generally follow synclinal axes.

Structural features control to a large extent the location of ground water recharge and discharge areas. Ground water entering a geologic formation tends to follow bedding planes because hydraulic conductivity is higher parallel to bedding than across bedding planes. Valleys in the area often lie on anticlinal axes, which provides a structural avenue for ground water to flow from one valley to another under ridges. Recharge to permeable rock outcrops on ridges may also follow fold structures and discharge in distant valleys. Fault structures affect the location of many springs.

REGIONAL PATTERNS OF GROUND WATER FLOW

Definite patterns of surface water and ground water flow are evident in the Western Phosphate Field. These ground water and surface water flow patterns are largely controlled by geology, hydrogeology, topography, and availability of recharge [3].

Precipitation on lee slopes supports flow in small surface channels and recharges ground water flow systems in the Dinwoody and overlying Thaynes Formation (mostly limestones and sandstones), the Wells Formation and colluvial deposits. Ground water within saturated colluvium moves down slope forming local flow systems. These local flow systems discharge as small springs or seeps. Many of these local ground water flow systems dry up during summer months.

Recharge which enters the Thaynes and Dinwoody formations forms local and intermediate ground water flow systems. Ground water within these formations moves down gradient following bedding planes and fault structures. Discharge from the flow systems is to springs and streams where bedding planes and faults intercept land surface. Some of the ground water within these flow systems moves across bedding planes into the lower member of the Dinwoody Formation. Further cross bedding flow is virtually prevented by the relatively low hydraulic conductivity of the Phosphoria Formation. Ground water commonly discharges along the Dinwoody-Phosphoria contact in the form of springs and increased stream flow.

The Meade Peak Member of the Phosphoria Formation supports no significant ground water flow systems. The Rex Chert Member may support localized flow systems where it is highly fractured. The Phosphoria Formation forms an effective hydrologic barrier between flow systems within the Thaynes and Dinwoody formations from those within the Wells Formation and underlying units. A possible exception to this is where considerable displacement has occurred due to faulting.

The Wells Formation supports major ground water flow systems within the area. These flow systems are believed to be regional in extent. Recharge to regional ground water flow systems in the Wells Formation occurs from precipitation, streamflow loss, and downward percolation from alluvial valley aquifers. The high mountains and valleys which receive the greatest precipitation are the principal recharge areas for regional flow systems. Discharge from regional flow systems is controlled largely by topography and structure.

Alluvial material in valleys contain large quantities of ground water. Surface water and ground water flow systems readily interact within alluvial materials. Some stream reaches within valleys lose to underlying alluvium while other reaches gain water from the alluvium.

WATER RESOURCE SYSTEMS AT SELECTED MINE SITES

Six mine sites within the southeastern Idaho phosphate field were studied to determine the relationship between pit and waste pile construction and the environmental factors controlling ground water flow systems [3]. The six mine sites examined are the (1) Dry Ridge-Maybe Canyon Mine, (2) Henry Mine, (3) Georgetown Canyon Mine (4) Wooley Valley Mine, (5) Conda Mine, and (6) Gay Mine (Figure 2). The first five mines listed are currently in operation; the Georgetown Canyon Mine is not.

All mine sites studied contain the "phosphate sequence" of sedimentary rock units consisting of the Dinwoody, Phosphoria and Wells formations. The sedimentary rock units in each area, except the Gay Mine, are part of a steeply dipping syncline-anticline sequence. In the Gay Mine area, the sedimentary sequence occurs in a broad gently dipping syncline which has been extensively block faulted. A generalized geologic cross section of each mine area is presented in figures 3 through 8. These cross sections are intended to show the basic geologic structure and the topographic profiles of each mine site so that similarities and contrasts between mine sites will be evident.

The geologic sections which occur at these mine sites may be grouped into three basic types. The types are where: (1) the sedimentary sequence dips into the major slope of the ridge and the Dinwoody and Phosphoria formations occur topographically higher than the Wells Formation, (2) the sedimentary sequence dips with the major ridge slope and the Wells Formation occurs topographically higher than the Phosphoria and Dinwoody formations, and (3) extensive faulting has occurred and the formations may dip with or against the topographic slope or lie almost horizontal. These three types of geologic structure significantly affect ground water flow systems.

The first geologic section type is characteristic of the Dry Ridge-Maybe Canyon Mine site (Figure 3) and three other proposed mine sites in the vicinity. The Phosphoria Formation at each of these sites dips into the ridge slope and the Thaynes and Dinwoody formations occupy the top of the ridges. The Dry Ridge-Maybe Canyon Mine is located on the southwest slope of Dry Ridge, which is the western limb of a large syncline. Here, mining occurs along the crest of a secondary ridge system which is located between Maybe Canyon and Dry Valley. The crest of a secondary ridge system which is located between Maybe Canyon and Dry Valley. The crest of this ridge is capped by the resistant Rex Chert Member of the Phosphoria Formation, which forms massive dip slopes into Maybe Canyon. The summit of Dry Ridge is located east of Maybe Canyon and is composed of the Thaynes and Dinwoody formations. In the vicinity of the mine pits, the Meade Peak Member of the Phosphoria Formation dips approximately 25 degrees to 40 degrees east.

Synclinal structures under ridges are generally found where rock units dip into the topographic slope. These synclinal structures, combined with the relatively low hydraulic conductivity of the Phosphoria Formation, act as basins which may hold significant quantities of ground water within the Dinwoody Formation. These factors apparently control the many local and intermediate ground water flow systems which are found in many of the ridges in the Western Phosphate Field. These ground water systems provide the base flow for most streams in this area.

The second geologic section type is characteristic of the Henry Mine, Georgetown Canyon Mine, Wooley Valley Mine and the northern portion of the Conda Mine (Figures 4, 5, 6 and 7). Rock units dip with the ridge slope at these mine sites. Outcrops of the Wells Formation occur topographically higher than the Phosphoria and Dinwoody formations. The Wells Formation and sometimes both the Wells Formation and the underlying Brazer Formation (limestone and sandstone) occupy the ridge tops and slopes above the mine pits and the Dinwoody Formation is found on slopes below the mine pits.

Ground water flow systems in mine areas where rock units dip with the topographic slope are significantly influenced by structure and outcrop pattern. The high hydraulic conductivity of the Wells and Brazer formations permits rapid infiltration of snow melt on the ridge tops. Water which recharges these formations percolates downward along bedding planes or zones of high hydraulic conductivity directly into regional ground water flow systems. The factors of high hydraulic conductivity, steep dip angles, and large thickness and areal extent of the formations all contribute to the movement of water from the ridge tops to regional ground water flow systems.
Mine sites which are located downslope from the Wells Formation have little surface runoff which enters the mine areas. This is especially true at the Georgetown Canyon Mine where a very large snowpack accumulates on the ridge top and slopes above the mine pits.
The Wells Formation and the Brazer Formation have such high hydraulic conductivity in this area that very little surface runoff from snowmelt reaches the mine pits. Streams on the slope above the mine pits rapidly lose flow to these formations. Large solution channels and a cave are evident in the footwall of mine pits in Georgetown Canyon Mine, illustrating the very high hydraulic conductivity.

The Dinwoody Formation outcrops downslope from the pit area in mine areas where rock units dip with the topographic slope. In this topographic position, the Dinwoody Formation supports fewer or smaller ground water flow systems than when it occupies synclinal structures under ridge tops. The springs and seeps which issue from the Dinwoody Formation below the mine pit areas of the Georgetown Canyon Mine and Henry Mine are generally very small.

Significant discharges do occur from the Dinwoody Formation in Little Long Valley near the Wooley Valley Mine site (Figure 6). However, these springs result from a flow system controlled by the synclinal feature under Rasmussen Ridge and are not related to the mining activity.

The third type of geologic section occurs in the Gay Mine area (Figure 8). Here, extensive block faulting has created an irregular topography where dips of rock units are moderate but may occur in almost any direction with respect to topographic slope. Either the Wells Formation or the Dinwoody Formation may occur topographically above the Phosphoria Formation. Complex geologic structure of this area greatly complicates ground water flow systems. Definite relationships between geologic factors and ground water flow systems are difficult to identify. Several small flow systems exist in the Dinwoody Formation in the Gay Mine area controlled by local faulting. A larger flow system exists in a structurally isolated block of Wells Formation rock. Recharge to these systems is primarily from direct precipitation. A thermal, mineralized spring indicates that some regional ground water flow occurs in the area, probably controlled by deep faulting.

All mine areas examined in this study, except the Gay Mine, are located on definite ridge systems with adjacent valleys. The mine sites which occupy ridges may be classified into three basic types based on the location of the mine pits relative to the topography of the ridge. These types are: (1) mine sites which occupy ridge tops, (2) mine sites which occupy the flank of a ridge, and (3) mine sites which occupy the base of a ridge or the edge of a valley floor. A fourth topographic type is needed for areas such as the Gay Mine where definite ridge and valley systems do not exist and mine pits may occupy several topographic positions. Each of these topographic classifications has associated with it distinct types of surface and ground water flow systems.

Only recharge to flow systems can occur at mine sites on ridge tops; all fluid potential gradients are directed downward and laterally. The Dry Ridge-Maybe Canyon Mine, which occupies the ridge top between Maybe Canyon and Dry Valley, falls into this category as does a portion of the Conda Mine on Woodall Mountain (Figures 3 and 7). No significant ground water flow systems discharge into mine pits along these ridge tops. Any precipitation and snowmelt entering the mine pits may be drained downward into underlying units using drain wells.

The second topographic classification encompasses all mine sites on the flanks of major ridges. Fluid potential gradients at these sites may be directed either upward or downward depending upon local topographic irregularities and geologic structure. Fluid potential gradients within these ridges are dominantly downward because the ridges are primarily recharge areas for local, intermediate, and regional ground water flow systems. Small discharge points in the form of seeps and springs are found on the ridge slopes of several mine sites including the Wooley Valley Mine, Conda Mine, and South Henry Mine (Figures 6, 4 and 7). Mine pits located on ridge flanks may intercept ground water discharge or they may induce ground water recharge depending upon their location relative to pertinent flow systems. Ground water flow systems which discharge into mine pits are generally local in extent on the upper portions of ridge slopes and become local to intermediate near the lower portions of ridge slopes. Most of the existing mines of this classification do not have major water problems.

The third topographic classification, for mine sites located at the base of a ridge or at the edge of a valley floor, is characteristic of several proposed mine sites in the Western Phosphate Field. Planned mine pits in the north portion of the Henry Mine area also fall into this classification. Fluid potential gradients at mine sites in this classification may have either upward, downward, or lateral components. Mine pits which penetrate significantly below the elevation of nearby valley floors may intercept regional ground water flow systems within the Wells Formation thus requiring significant dewatering operations.

The Gay Mine is the only site where mining has been limited by pit flooding. Pit dewatering operations have been necessary where mining has continued to depths below the water table in the structurally isolated block of the Wells Formation. The dewatering has only been partially successful because of the high hydraulic conductivity of the Wells Formation.

CONCLUSIONS

1. A distinct pattern of ground water flow systems exists in the Western Phosphate Field based upon regional consistencies in the hydrogeologic properties of the Dinwoody, Phosphoria and Wells formations.

2. The low hydraulic conductivity Phosphoria Formation acts as a ground water barrier over most of the region separating flow systems in units stratigraphically above from those in units stratigraphically below.

3. The ground water flow systems at the six mines evaluated may be classified into three groups based upon the type of geologic section present at the mine.

4. Significant ground water flow systems are usually present in the Dinwoody Formation at those mine sites where the sedimentary sequence dips into the major slope of the ridge.

5. Very little surface water or ground water is evident at mines where the rock units dip with the topographic unit. Considerable recharge occurs where the high hydraulic conductivity Wells Formation is exposed along ridge tops.

6. The relative location of a mine with respect to topography also controls the nature of flow systems intercepted during pit construction. Most of the phosphate mines are located in recharge areas; any precipitation and snowmelt entering the mine pits may be drained downward into underlying units using drain wells.

REFERENCES

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[3] Ralston, D. and others. Interactions of Mining and Water Resource Systems in the Southeastern Idaho Phosphate Field. Idaho Water Resources Research Institute, Moscow, p. 214 /1980/

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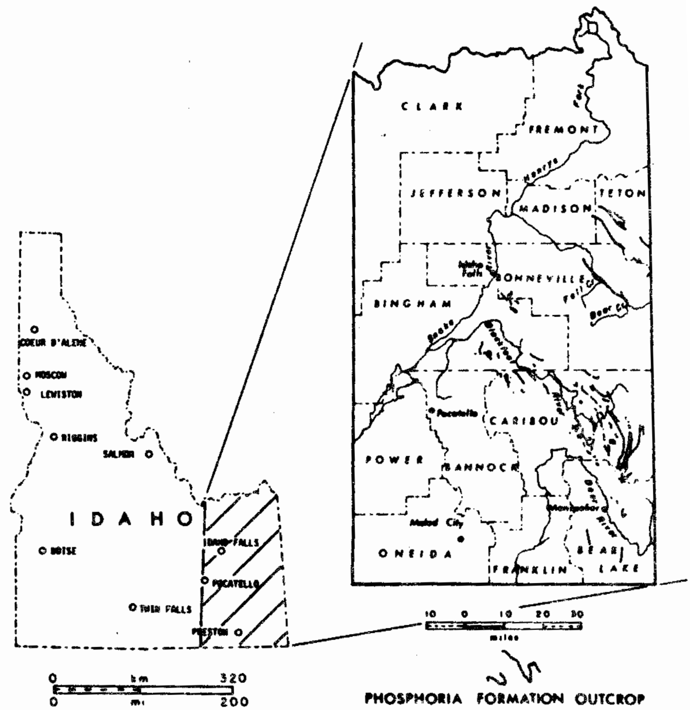


Figure 1. Location of Phosphoria Formation outcrops in the southeastern Idaho phosphate field [3]

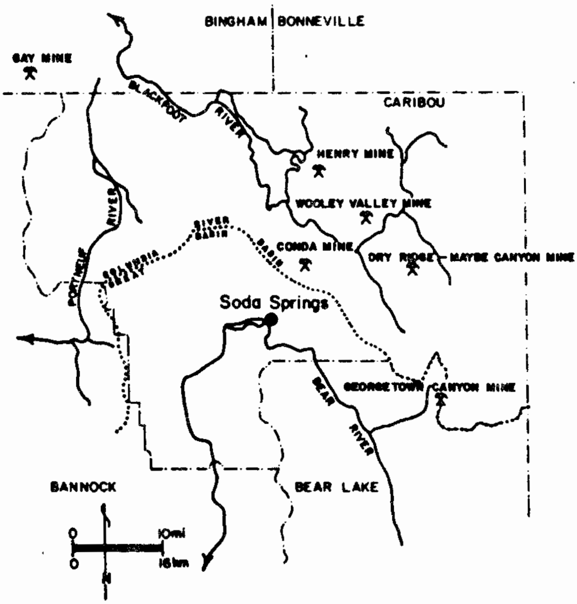


Figure 2. Location of mine sites in the study area [3]

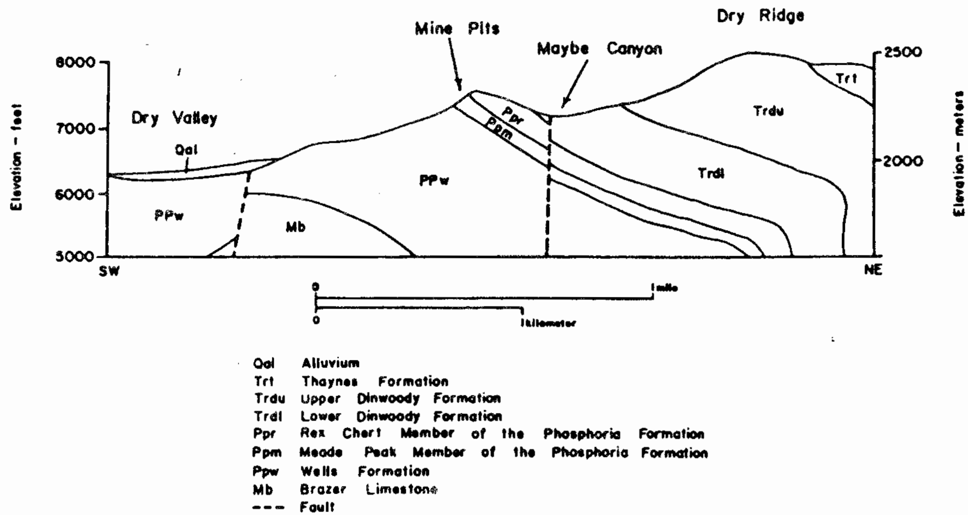
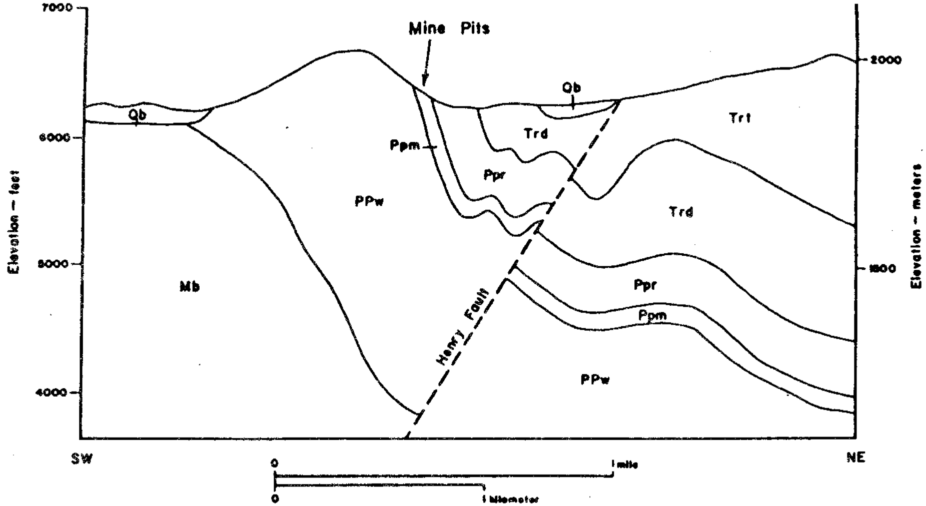
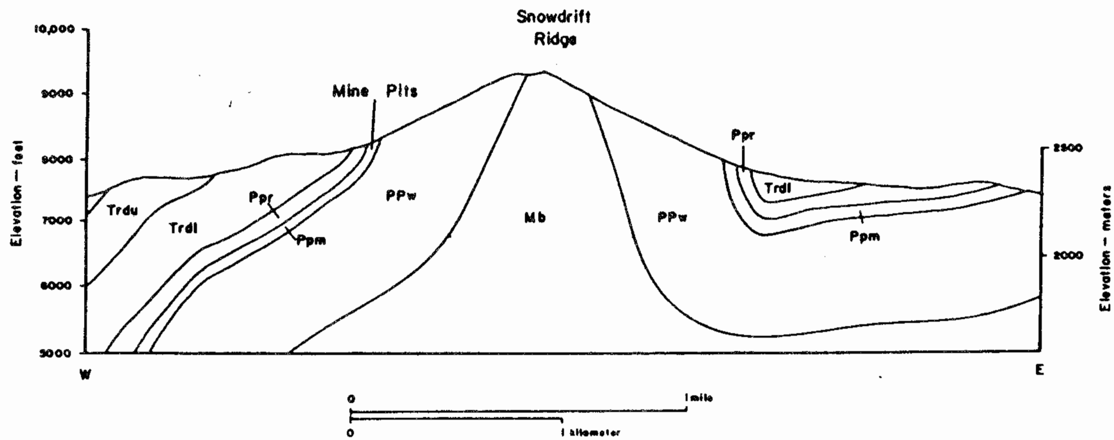


Figure 3. Generalized geologic section through Dry Ridge-Maybe Canyon Mine site [3]



Qb	Basalt
Trt	Thaynes Formation
Trd	Dinwoody Formation
Ppr	Rex Chert Member of the Phosphoria Formation
Ppm	Meade Peak Member of the Phosphoria Formation
PPw	Wells Formation
Mb	Brazer Limestone

Figure 4. Generalized geologic section through North Henry Mine site [3]



Trdu	Upper Dinwoody Formation
Trdl	Lower Dinwoody Formation
Ppr	Rex Chert Member of the Phosphoria Formation
Ppm	Meade Peak Member of the Phosphoria Formation
PPw	Wells Formation
Mb	Brazer Limestone

Figure 5. Geologic section through the Georgetown Canyon Mine site [3]

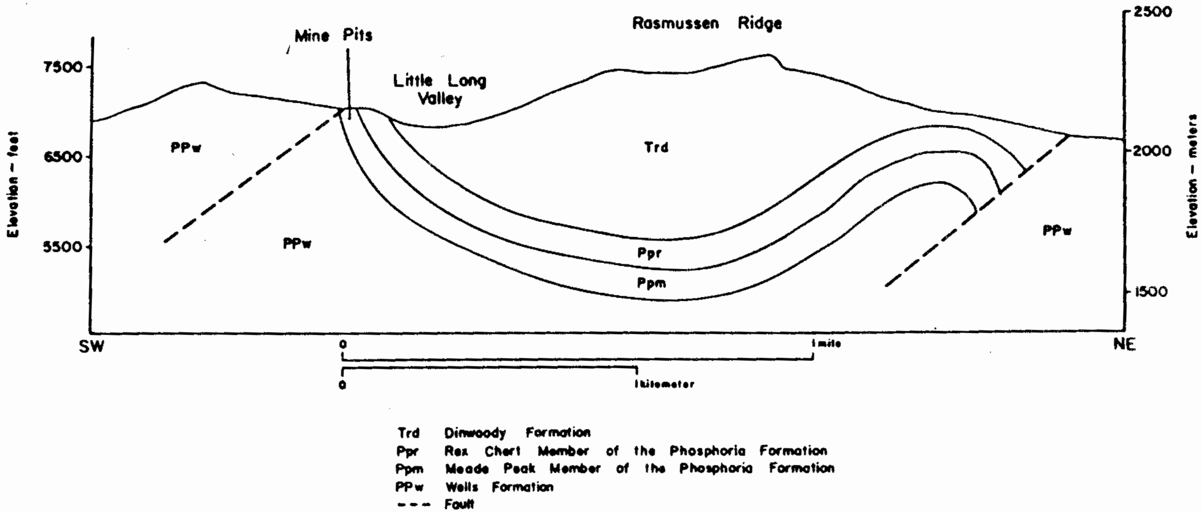


Figure 6. Generalized geologic section of the Wooley Valley Mine area [3]

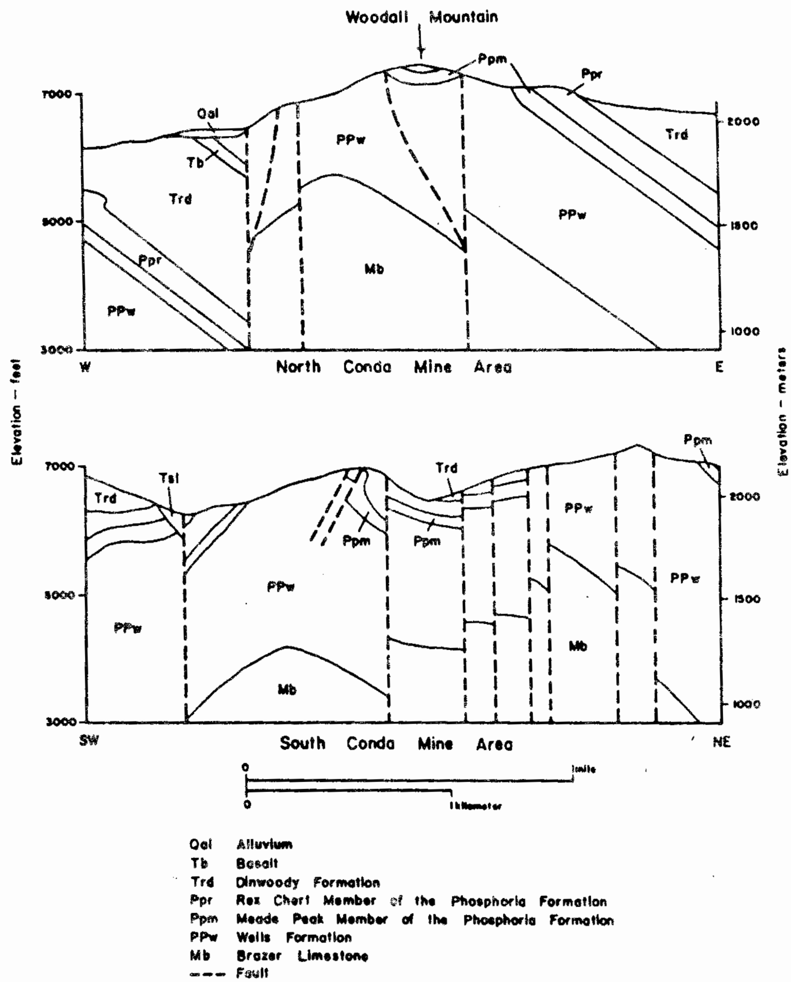
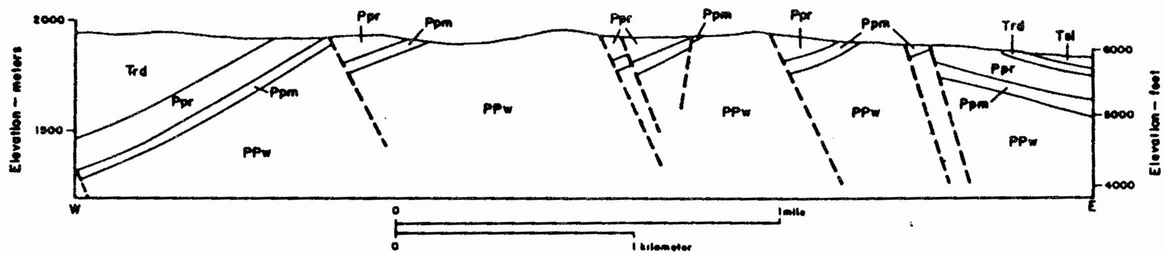


Figure 7. Geologic sections through north and south Conda Mine areas [3]



Tsl Salt Lake Formation
Trd Dinwoody Formation
Ppr Rex Chert Member of the Phosphoria Formation
Ppm Meade Peak Member of the Phosphoria Formation
PPw Wells Formation
--- Fault

Figure 8. Generalized west-east geologic section through the Gay Mine [3]