GEOLOGY AND HYDROGEOLOGY OF THE MOSCOW EAST AND ROBINSON LAKE QUADRANGLES LATAH COUNTY, IDAHO

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JACK L. PIERCE

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AUTHORIZATION TO SUBMIT
THESIS

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ABSTRACT

The primary source of water in the Moscow-Pullman basin comes from a deep aquifer system referred to as the Grande Ronde aquifer and an upper aquifer system referred to as the Wanapum aquifer. Overlying and in contact with the upper aquifer are loess deposits with fluvial and lacustrine sediments. This study focuses on the geological and hydrological aspects of these overlying sediments and the upper aquifer in the eastern portion of the Moscow-Pullman basin. The study area is located on portions of the Moscow East and Robinson Lake 7.5 minute quadrangles.

The study area lies on the eastern edge of the Columbia Plateau where Miocene basalt flows (Columbia River Basalt Group) overlie Precambrian and Cretaceous basement rocks. Interbedded with and overlying the basalt flows are the sediments of the Latah Formation which were deposited in response to the invading lava flows. An isopach and sand/clay percentage map was constructed for the upper most sedimentary unit informally referred to as the sediments of Bovill.

Water levels in 41 domestic wells that penetrate the Wanapum aquifer were measured several months apart to observe water level trends and evaluate recharge potential to the basin. Measurements suggest varying water level trends throughout the study area with rapid recharge proximal to the basin margin and less recharge response in wells located away from the margin.

The results of this study suggest the sediments of Bovill play an important

role for recharge into the groundwater system of the Moscow-Pullman basin. These sediments consist of clay, silt, sand and gravel. In general, they are coarse-grained near the margins of the basin where recharge is expected. Present day drainage across the eastern portion of the basin follows the coarse grain facies of the sediments of Bovill. Recharge is also expected along the flood plains of those drainages.

Continued monitoring of water level trends, maintaining lithologic records of new well logs and further hydrological investigations will increase the accuracy of lithologic contacts and hydrologic properties.

TABLE OF CONTENTS

INTRODUCTION

GEOLOGY

HYDROGEOLOGY

LIST OF FIGURES

LIST OF TABLES

LIST OF PLATES

INTRODUCTION

Location and Statement of the Problem

The Moscow-Pullman basin, located in Eastern Washington and northern Idaho, lies along the eastern margin of the Columbia Basin. Essentially all municipal and domestic water is derived from wells completed in basalt of the Columbia River Basalt Group. Recharge to these aquifers is of concern because of continual water level decline throughout the entire basin. Surface sediments play an important role in controlling recharge rates. This study involves development of a better understanding of the geologic setting of the eastern portion of the basin, with specific emphasis on the surface sediments.

The Moscow East and Robinson Lake quadrangles are located in southwestern Latah County of northern Idaho. Parts of these quadrangles comprise the eastern end of the Moscow-Pullman basin. This eastern area herein is referred to as the study area. The Moscow-Pullman basin, referred to as the basin, extends westward from the study area into eastern Washington (Figure 1). The city of Moscow is located within the study area in the Moscow East quadrangle and extends westward into the adjacent Moscow West quadrangle (Figure 1).

The primary source of water in the basin comes from groundwater which occurs in a deep and shallow aquifer system. The shallow aquifer is located in basalt flows of the Wanapum Formation and the deep aquifer is located in basalt flows of the Grande Ronde Formation. These basalts belong to the Columbia

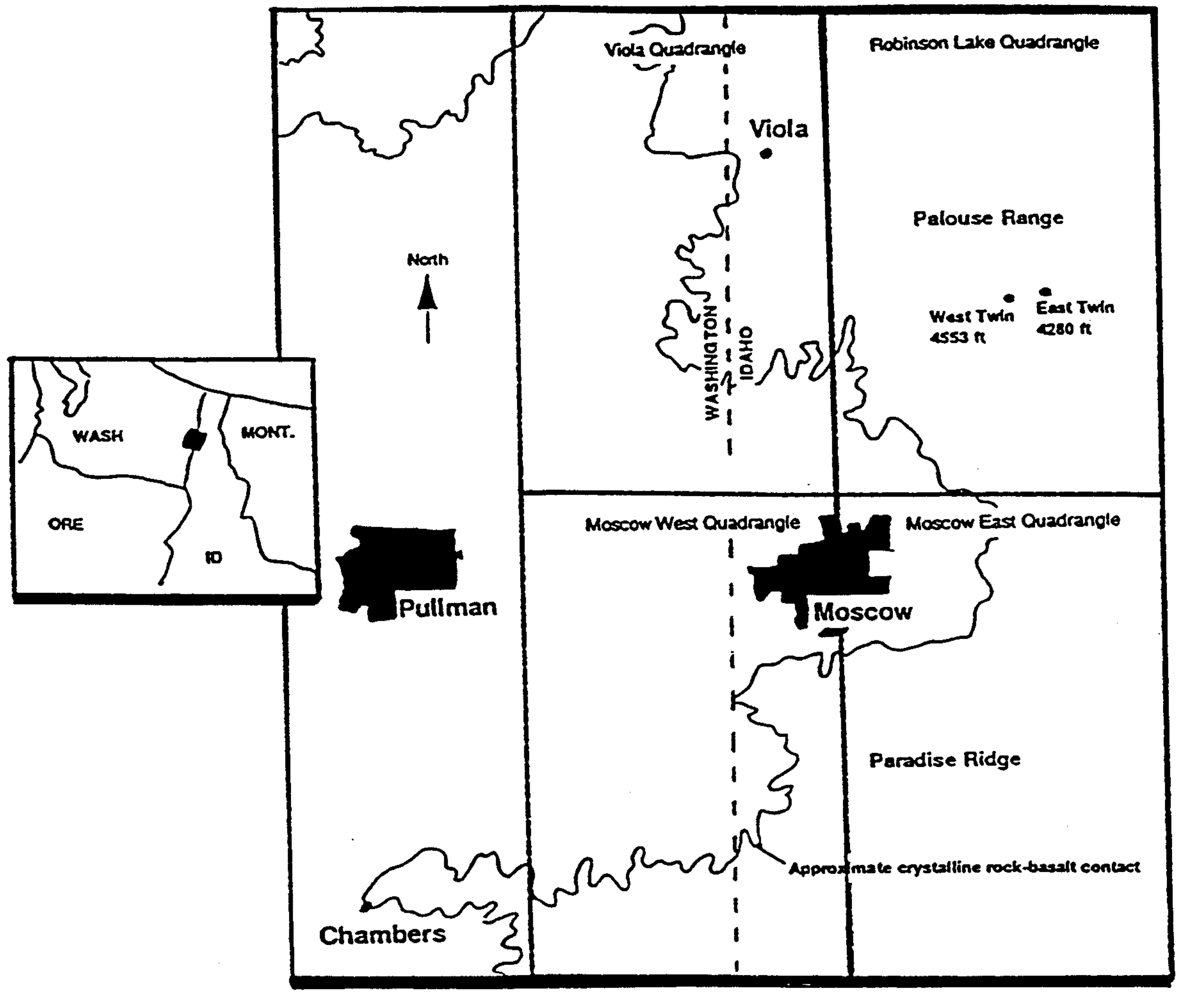


Figure 1. Location map showing the Moscow East and Robinson Lake quadrangles, Moscow and study area. Illustrated is the boundary between the basement crystalline rocks to the east and the overlying basalt to the west. This boundary defines the eastern boundary of the Moscow-Pullman basin. (Scale: 1 inch = 4 miles)

River Basalt Group and are interbedded with sediments of the Latah Formation. In the past several years the basin and surrounding areas have been the focus of several hydrologic studies. These studies have made important contributions to the hydrogeologic knowledge of the basin. However, there are still problems in predicting long term draw-downs and recharge within the basin. This report approaches these problems, in part by investigating the geology and hydrogeology of the study area.

Purpose and Objectives

The purpose of this thesis is to provide additional information on the complex hydrogeology that characterizes the basin. The general objectives are to: produce two interpretive geologic base maps and cross-sections at a scale of 1:24,000 and describe how the geologic setting controls groundwater conditions. This report is intended to assist planners, developers and public officials for investigative uses concerning area planning and the future of water resources. Specific objectives are as follows:

1. Construct interpretive geologic base maps of the Moscow East and Robinson Lake 7.5 minute quadrangles at a scale of 1:24,000.
2. Produce geologic cross-sections, isopach and facies maps depicting the shallow subsurface geologic and hydrogeologic conditions.
3. Conduct an inventory of wells within the study area that primarily focuses on water levels and locations of new and existing wells completed in the upper basalt (Wanapum Formation) and overlying sediments.

4. Present the geology and hydrogeologic setting of the study area with particular emphasis on the upper most shallow sediments.
5. Present specific conclusions and recommendations.

Physiography

Rolling hills and steeply rising mountains form the topographic relief within the Moscow East and Robinson Lake quadrangles. Rolling hills cover portions of both quadrangles and are composed of a layer of loess deposits with a maximum thickness of about 61 meters (200 feet). Mountains in the area, composed of resistant crystalline basement rock, form an amphitheater-like feature that surrounds the city of Moscow. These crystalline rocks define the eastern limits of the Moscow-Pullman basin.

The South Fork of the Palouse River and Paradise Creek are the two major drainage systems within the study area. The South Fork of the Palouse River flows from the south-western slope of Moscow Mountain, traverses through the southern area of the Robinson Lake quadrangle and enters the Moscow East quadrangle and abruptly changes to a westerly direction. Paradise Creek lies within the study area and is the only perennial stream. Other streams are intermittent, flowing only at times of high precipitation of snow melt during winter and spring months.

Previous Investigations

Geology

Regional maps and petrographic studies of portions of Latah County are presented by Tullis (1940; 1944). Hosterman and others (1960) investigate clay deposits (Canfield-Rogers deposit) in the Moscow East Quadrangle. Rember and Bennentt (1979) compile the geology of the Pullman quadrangle at a scale of 1:250,000. Swanson and others (1977; 1979a; 1980) provide a map at a scale of 1:250,000 and subdivide the Columbia River Basalt Group in southeast Washington and adjacent areas of Idaho. Swanson and others (1979b), Hooper and Webster (1982) and Reidel and Fecht (1987) describe stratigraphic terminology of the Columbia River Basalt Group. Anderson (1991) presents the geology and structural analysis of the Tomer Butte, Middle Potlatch Creek and Little Potlatch Creek Areas located in the central part of the Moscow East quadrangle (Plate 1).

Hydrogeology

Russell (1897) completed the first hydrogeology investigation of the basin; he noted that 10 out of 14 wells drilled were flowing artisan wells in 1895. By 1896, water levels had declined reaching depths of 2.4 meters to 2.7 meters (8 to 9 feet) below land surface. Foxworthy and Washburn (1963), Ross (1965), Walters and Glancy (1969), and Jones and Ross (1969, 1972) present descriptions of the basic hydrogeology within the area.

Geologic well logs, well construction data, water levels in observation wells, brief overviews of the geology and hydrogeology and various aspects of water supply in the Moscow-Pullman basin is completed by Laney and others (1923), Stevens (1960), and Crosthwaite (1975). Jones and Ross (1972), Barker (1979), Smoot and Ralston (1987), and Lum and others (1990) show various mathematical models demonstrating groundwater flow within the basin. Baines (1992) demonstrates that safe yield in the upper aquifer is greater than the current pumpage. This analysis is based on historic pumpage and water level records.

Kopp (1994) reports the detailed hydrogeology of the upper aquifer, based on data from the Aquaculture Research Facility and the Groundwater Research Site at the University of Idaho. Data from this research shows that the low value of hydraulic conductivity within the center of the upper most basalt flow is a primary control for the rate of water movement from the surface to the upper aquifer. Hinemann (1995) describes the relationship of streams in parts of the western Moscow-Pullman basin to the two aquifer systems.

Well-Numbering System

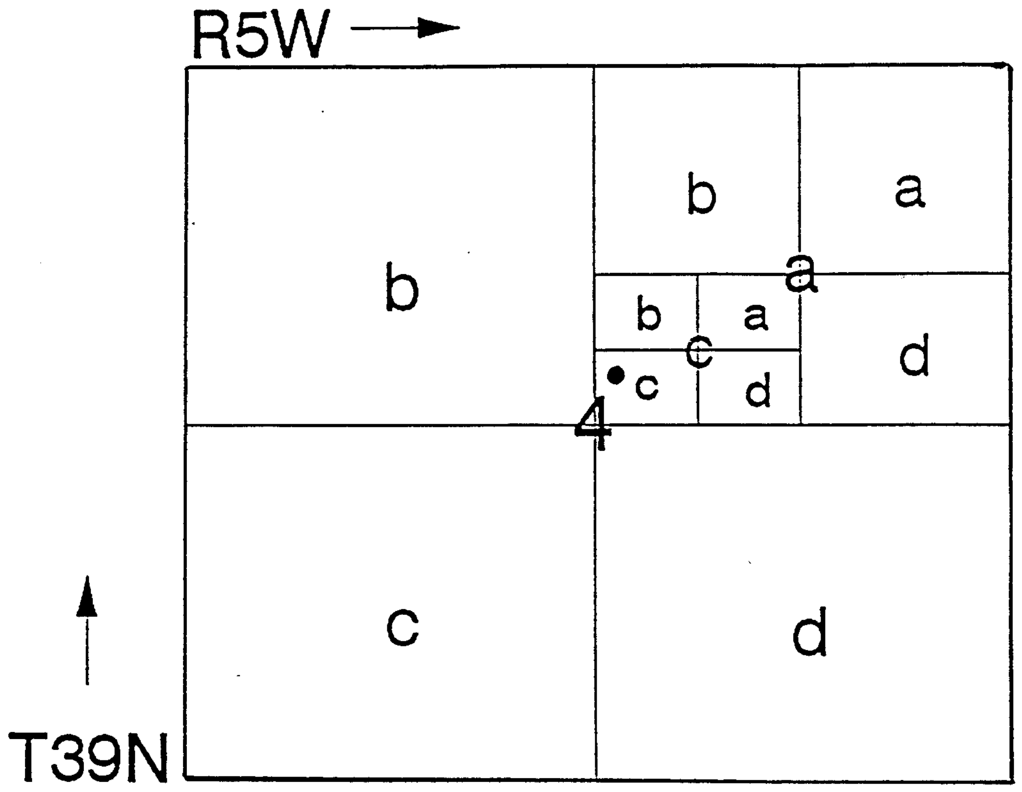
The State of Idaho describes the location of wells using the Public Land Survey System. This report uses the Public Land Survey System to denote the township, range and section with reference to the Boise meridian and baseline. Letters denoting the quarter-quarter section begin in the northeast corner and follow around in a counter-clockwise direction in alphabetical order. This counter-clockwise method of quartering is used for quarter-quarter and quarter-quarter-quarter sectioning. Figure 2 shows a typical location of a well using the Public Land Survey System to the nearest quarter-quarter-quarter section.

Method of Study

Research began in May of 1994. Field investigation (mapped rock exposures and lithologic descriptions) of both the Moscow East and Robinson Lake quadrangles was conducted over the summer of 1994 with periodic field work throughout the winter months. Identifying and mapping various rock exposures, analysis of well logs and previous investigations allowed the construction of interpretive geologic base maps for the Robinson Lake and Moscow East quadrangles at a scale of 1:24,000 (Plates 1 and 2). Cross-section analysis through portions of these quadrangles, and isopach and sand/clay percentage maps were completed by interpretation of well logs and field relations (Plates 1,2,3 and 4).

Well Inventory

The second part of the investigation involved a well inventory within the study area. This data base includes information on the geology and hydrogeology of the shallow sediments and upper aquifer. The well inventory data base consists of well location, elevation, depth of penetration into the upper basalt (Priest



Well Location: (39N–5W–4acc1)

Figure 2. Typical well location using the Public Land Survey System to the nearest quarter-quarter-quarter section. Well location shows Township-Range-Section-quarter sections.

Rapids Member) and previous water level measurements. Well inventory data regarding the Moscow West, Viola and Pullman quadrangles can be found in Provant (1995). Annual water levels and pumped gallons for municipal wells in Pullman, Moscow and the two Universities can also be found in Provant (1995).

GEOLOGY

Introduction

Presented in this section are descriptions, map locations and cross-section analysis of major geologic units identified within the Robinson Lake and Moscow East quadrangles. These units are as follows: Precambrian rocks which consist of varying proportions of schist, gneiss and quartzite, Precambrian-Cretaceous mixed units, Mesozoic intrusive rocks, Miocene Columbia River Basalt flows with associated sedimentary units of the Latah Formation and the Pleistocene Palouse Loess and Holocene alluvium.

Description of Map Units

The geologic base maps of the Moscow East and Robinson Lake quadrangles (Plates 1 and 2) do not show the loess deposits of the Palouse Formation in order to produce an interpretive geologic base map, but a lithologic description is presented herein. The maps represent a compilation of pre-existing works, new and existing well data and additional field work. The chemical analysis for basalt units were completed by the GeoAnalytical Laboratory at Washington State University. Description of map units are in stratigraphic sequence from base upwards.

Crystalline Rocks

Precambrian Quartzite (PCq)

Precambrian Quartzite (PCq) exposures occur in the middle portion of the Robinson Lake quadrangle (Plate 2). They form a prominent topographic feature that is surrounded by Idaho batholith rocks. This unit is composed almost entirely of recrystallized quartz grains. Quartz grains are medium to coarse-grained and highly fused together when seen in hand sample. Outcrops of a similar unit were noted in the adjacent Viola quadrangle mapped by Provant (1995). This unit is interpreted to be roof pendant material uplifted by Cretaceous Idaho batholith rocks.

Precambrian Quartzite, Schists and Gneiss (PCqsg)

Numerous quartzite units have been mapped within areas of Whitman and Latah Counties. These include Tomer Butte on the Moscow East quadrangle (Plate 1) mapped by Anderson (1991), and the northern area of the Robinson Lake quadrangle (Plate 2). Illustrated as PCqsg on Plates 1 and 2, regional examination of the outcrops show quartzites interbedded with less resistant schist and gneiss. The quartzite is composed of approximately 95-99 percent recrystallized quartz. Biotite locally composes up to 5 percent and accessory minerals are muscovite, hematite, zircon and apatite. In hand sample, the quartzite is medium to coarse-grained, with grains ranging in size from 2mm to 8mm showing moderate to strong foliation trends. Illustrated on the Moscow East quadrangle (Plate 1) are foliation trends primarily from Anderson (1991) Tullis (1944) postulates that these Precambrian units (PCqsg) are a member of the Prichard Formation of the Belt Supergroup. Bond (1963) shows these quartzite units as pre-Belt basement rocks. Hooper and Webster (1982) note quartzite exposures on Paradise Ridge, approximately 3 kilometers south of Moscow, and suggests a Cambrian age. Anderson (1991) suggests they are equivalent to the Revett Formation of the Belt Supergroup.

Correlation of this unit (PCqsg) is difficult. In places quartzite dominates the exposures because they are the resistant rocks. However, the schist and gneiss may in many places be the dominate lithology. Field work on the northern parts of the Robinson Lake and Viola quadrangles suggest the quartzites are interbedded with schist and gneiss that are Precambrian in age.

Precambrian-Cretaceous Mixed Rocks (Kpcm)

Mixed rocks consist of intermixed Precambrian biotite, muscovite gneiss and schist with Cretaceous gneissic granitoid rocks. General foliation in the granitoid units both follow and cross-cut pre-intrusive foliation of the schist and gneiss. In places these rocks are locally weathered to a micaceous, quartz bearing kaolinite clay. Diopside and minor garnet bearing units are locally present. Granitic textures range from equigranular to pegmatitic. Outcrop patterns have been extrapolated from the adjoining Troy quadrangle (Bush and Priebe, 1995).

Although exposures are rare within both quadrangles, mixed rocks crop out along the margin of the crystalline basement in the north-central section of the Moscow East quadrangle (Plate 1). Foliation consistently trends north-east with steep to vertical dips. The best exposure occurs on the Elks Club Golf course in an ongoing excavation pit, just south of the Mill Road and Robinson Lake Road intersection. These rocks may extend westward, but their less resistant nature and the erosional effects of the South Fork of the Palouse River probably have reduced the outcrop to its present day map pattern (Plate 1). In the northern area of the Robinson Lake quadrangle (Plate 2) exposures of Precambrian-Cretaceous mixed rocks are proximal to intrusive rocks which are part of the Idaho batholith (Plate 2). The Precambrian-Cretaceous mixed rocks can be regarded as Precambrian units intruded by Cretaceous granitic magmas which created their textures and range of compositions.

Intrusive Rocks (Kgr)

Intrusive rocks within the study area are believed to have formed during the Cretaceous period (Hooper and Webster, 1982). These igneous bodies are composed primarily of quartz tonalite and hornblende granodiorite (Tullis, 1944). In places foliation is common. Grain sizes range from medium-grained equigranular to coarse-grained equigranular. Tonalites within the area are composed of quartz, andesine, muscovite and biotite. Orthoclase, quartz and muscovite bearing pegmatite veins are locally present, but commonly found within the tonalite bodies.

Exposures of intrusive rocks primarily occur in the eastern section of both quadrangles. These rocks comprise approximately 70 percent of the Robinson Lake quadrangle (Plate 2) and form the east-west trending Palouse Range which extends into the adjacent Moscow Mountain quadrangle. On the Moscow East quadrangle (Plate 1) intrusive rocks are located to the east and south of the study area and form Paradise Ridge (Plate 1). The northern granitic-basalt contact (Plate 2) was interpreted using geophysical data extrapolated from Bochius (1985). The granitic-basalt contact in the remainder of the study area (Plates 1 and 2) has been extrapolated from field work and current well data.

The intrusive rocks in both quadrangles are considered part of the Idaho batholith which forms part of the underlying basement complex beneath the basin (Plates 1 and 2). This relation is illustrated from the interpretation of well data. Moscow City well 6 (39N-5W-8bdb1) is the deepest well at 399 meters (1308 feet) completed in the study area. This well does not encounter the basement rocks, therefore it is necessary to extrapolate the lateral extent of the underlying basement rocks in the study area from deeper wells completed in the adjacent Moscow West quadrangle. Moscow City well 8 (39N-5W-7bda2) and the University of Idaho well 3 (39N-5W-7dad3) have penetrated the underlying basement complex at approximately 427 meters (1400 feet). From this observation, the contact with the underlying basement rocks can be laterally extrapolated eastward into the Moscow East quadrangle at least to a depth of

427 meters (1400 feet) and interpreted to gradually rise to the surface. The granitic basement rocks underlie formations of the Columbia River Basalt Group and associated sediments of the Latah Formation.

Columbia River Basalt Group

The Columbia River Basalt Group comprises a sequence of basalt flows which erupted from fissures during an 11-million-year period of the Miocene Epoch (Baski, 1989). The bulk of the basalt was erupted in the first 1.5 million years (Baksi, 1989). Figure 3 shows the regional extent of the Columbia River Basalt Group. These flows invaded valleys, ponding and damming streams, which in turn caused sedimentation around the edges of the plateau.

The stratigraphic nomenclature for the Columbia River Basalt Group in the Moscow-Pullman basin is based on the formal nomenclature presented by Swanson and others (1979b), Reidel and Fecht (1987) and Riedal and others (1989). From base upward, these are the Imnaha, Grande Ronde, Wanapum and Saddle Mountains Formations. The Grande Ronde Basalt is a sequence of flows that erupted between 15.6 Ma and 17.0 Ma (Reidel and others, 1989). The Wanapum Basalt is a series of flows that erupted between 14.5 and 15.6 Ma (Swanson and others, 1979a and Tolan and others, 1989). The Saddle Mountains Basalt is a series of flows that erupted between 6.0 Ma and 14.5 Ma (Swanson and others, 1979a and Tolan and others, 1989).

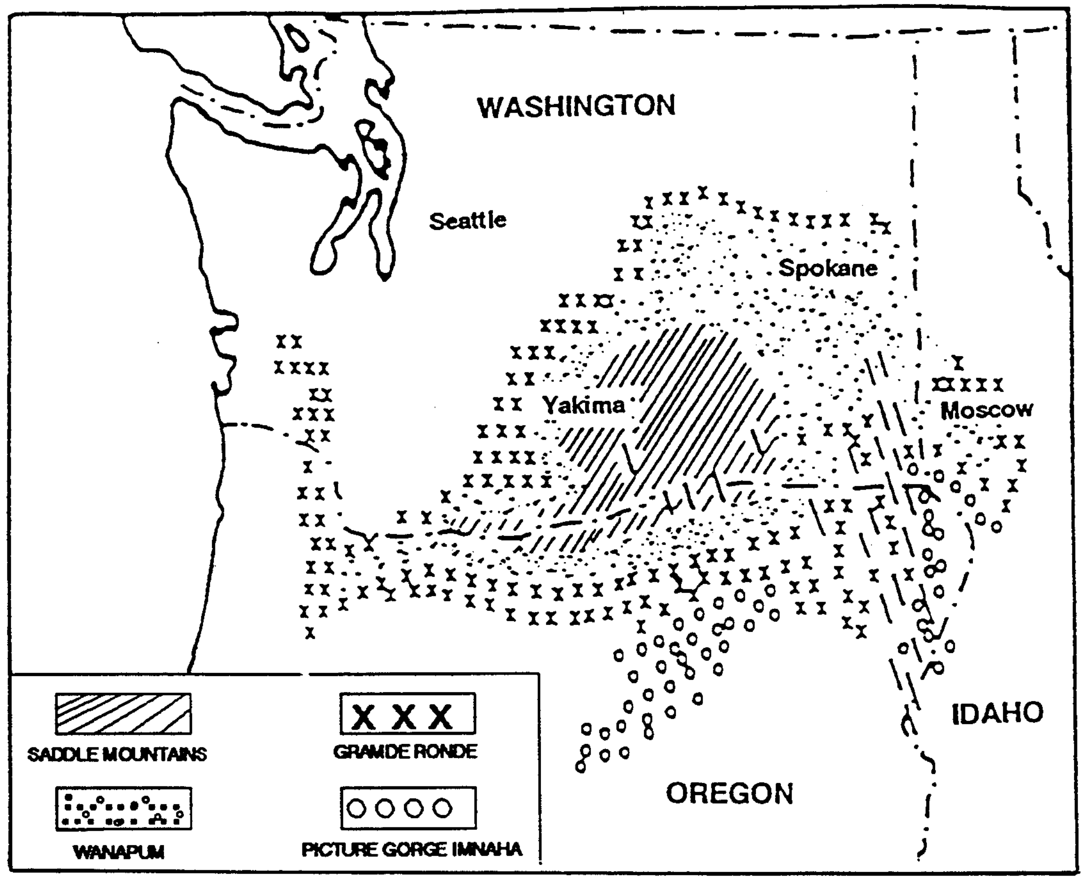


Figure 3. Generalized distribution of Columbia River Basalt Group (Saddle Mountains, Wanapum, Grande Ronde, Picture Gorge, Imnaha). Solid northwest-striking lines indicate the locations of abundant vents. After Bush (1992).

Three formations of the Columbia River Basalt Group are found in areas of both quadrangles. These are the Grade Ronde, Wanapum and the Saddle Mountains Formations

Grande Ronde Formation (Tgr$_2$)

This formation consists of fine-grained to very fine-grained aphyric flows of Grande Ronde chemical type (Wright and others, 1973; Swanson and others, 1977, 1979b). No exposures of the Grande Ronde have been noted in the study area. In the central-eastern portion of the Moscow East quadrangle (Plate 1), the Grande Ronde Formation has been mapped by projecting the unit from exposures previously mapped in the adjoining Troy quadrangle by Bush and Priebe (1995).

The Grande Ronde is encountered in the subsurface. The cross-sectional view (Plate 1) of the Grande Ronde Formation has been interpreted from Moscow and University of Idaho wells. The cross-sectional depiction of the Grande Ronde Formation south of Paradise Ridge is interpreted from deep wells completed throughout the study area.

The stratigraphic features of the Grande Ronde Formation are interpreted using well data from Moscow City well 6 (39N-5W-8bdb1) located within the study area. The first contact of the Grande Ronde Formation occurs 183 meters (600 feet) below the surface. This section of basalt is 14 meters (50 feet) thick and underlies a section of interbedded sediment 93 meters (305 feet) thick. The second contact of Grande Ronde Basalt occurs 276 meters (675 feet) below the surface and is 68 meters (233 feet) thick. Underlying this section is 55 meters (180 feet) of interbedded material representing the completed portion of the well.

The top of the Grande Ronde Formation was encountered at 198 meters (649 feet) below the surface in city well 8 and 177 meters (580 feet) below the surface in the University well 3. Basalt units shown in both well logs are approximately 24 meters (78 feet) thick above underlying sediments indicating they are the same flow. The top of the thickest portion of Grande Ronde Basalt is encountered at 290 meters (951 feet) below the surface at Moscow City well 8 (39N-5W-7bda2) and 271 meters (888 feet) below the surface in University Idaho well 3 (39N-5W-7dad3). This slight elevation difference of 18 meters (59 feet) suggests a westerly or north-westerly dip of about one degree. Data from Moscow City wells 8 (39N-5W-7bda2) and 6 (39N-5W-8bdb1) coupled with data University of Idaho well 3 (39N-5W-7dad3) allows extrapolation of the Grande Ronde into the study area (Plate 1).

Well data described above indicate the Grande Ronde is laterally continuous with associated interbedded sediments to the east. However, wells completed in the more eastern parts close to crystalline rocks indicate a thinning upper basalt unit and thickening of associated sediments. Plate 1 shows a cross-sectional view of the Grande Ronde Formation, the overlying Wanapum Formation, and associated sediments of the Latah Formation.

Wanapum Formation

In the Moscow area, the Wanapum Formation consists of the Priest Rapids Member (Tpr) which is primarily made up of one to three flows (Hooper and Webster, 1982). The member is characterized by medium-grained basalt with small phenocrysts of plagioclase and olivine in a matrix of intergranular pyroxene, ilmenite blades and minor devitrified glass. South of Paradise Ridge, the uppermost exposures are very coarse-grained compared to lower elevation outcrops suggesting at least two flows. This upward coarsening is similar to relations determined on the adjoining Troy quadrangle (Bush and Priebe, 1995). Reitman (1966) demonstrates that these flows have reversed magnetic polarity. Twelve outcrops within the Moscow East quadrangle were analyzed for major and minor trace elements and are shown in Table 1. Plate 1 shows the location of each sample. Samples six and seven were very weathered resulting in chemical data that are not consistent with the Priest Rapids Member.

The Priest Rapids Member underlies much of the study area with few surface exposures. Major exposures within the Moscow East quadrangle (Plate 1) occur in a valley located at the eastern section where highway 8 traverses through Joel. South of the study area along Little Potlach Creek (Plate 1) the Priest Rapids Member is exposed in a quarry and is interpreted to fill paleo-drainages up to an elevation of approximately 2700 feet above sea level (Plate 1). The eastern section of Plate 1 shows the Priest Rapids Member at elevations of 2800 feet. This elevation difference or rise may indicate that the member lies on the

Table 1. Major Element Analysis of Priest Rapids Member, Moscow East Quadrangle, Latah County, Idaho. **

Location Number	Si02	Al203	Ti02	Fe0*	Mn0	Ca0	Mg0	K20	Na20	P205
B1	50.85	13.46	3.23	13.37	0.22	9.19	5.11	1.07	0.97	0.78
B2	49.97	13.69	3.28	13.70	0.24	9.27	5.40	0.97	2.69	0.79
B3	50.58	13.84	3.29	12.94	0.22	9.32	5.15	1.1	2.76	0.81
B4	50.61	13.44	3.27	14.13	0.24	9.12	4.50	1.19	2.67	0.82
B5	50.24	14.65	3.45	13.18	0.22	9.88	3.36	1.32	3.08	0.82
B6	51.49	13.99	3.21	12.54	0.22	9.06	4.70	1.24	2.73	0.81
B7	53.87	16.17	3.87	8.93	0.14	10.07	1.66	1.37	3.03	0.84
B8	51.02	16.02	3.85	9.41	0.16	10.01	3.35	0.89	2.88	0.89
B9	51.12	13.56	3.25	13.44	0.22	9.24	5.14	1.08	2.69	0.78
B10	50.38	13.89	3.31	13.81	0.24	9.35	5.44	0.98	2.71	0.79
B11	50.92	13.93	3.31	13.03	0.22	9.38	5.19	1.11	2.78	0.82
B12	50.71	13.47	3.27	14.16	0.24	9.14	4.51	1.19	2.68	0.83

* Total Fe is expressed as Fe0

** All analysis done at Washington State GeoAnalytical Laboratory

up-thrown side of a fault extrapolated from the adjacent Troy quadrangle. The total thickness of the Priest Rapids Member is determined from wells located in the study area (Figure 4). In the western section of the study area, thickness of Priest Rapids Member encountered in Moscow well 4 (39N-5W-8ddd) and Moscow well 6 (39N-5W-8bdb) are 55 meters (180 feet) and 53 meters (173 feet) respectively. In the Sunset Memorial Garden well (39N-5W-17daa) and the Parker farm well (39N-5W-15bc1), in the eastern portion of the study area, thicknesses are 56 meters (186 feet) and 54 meters (177 feet) respectively. The

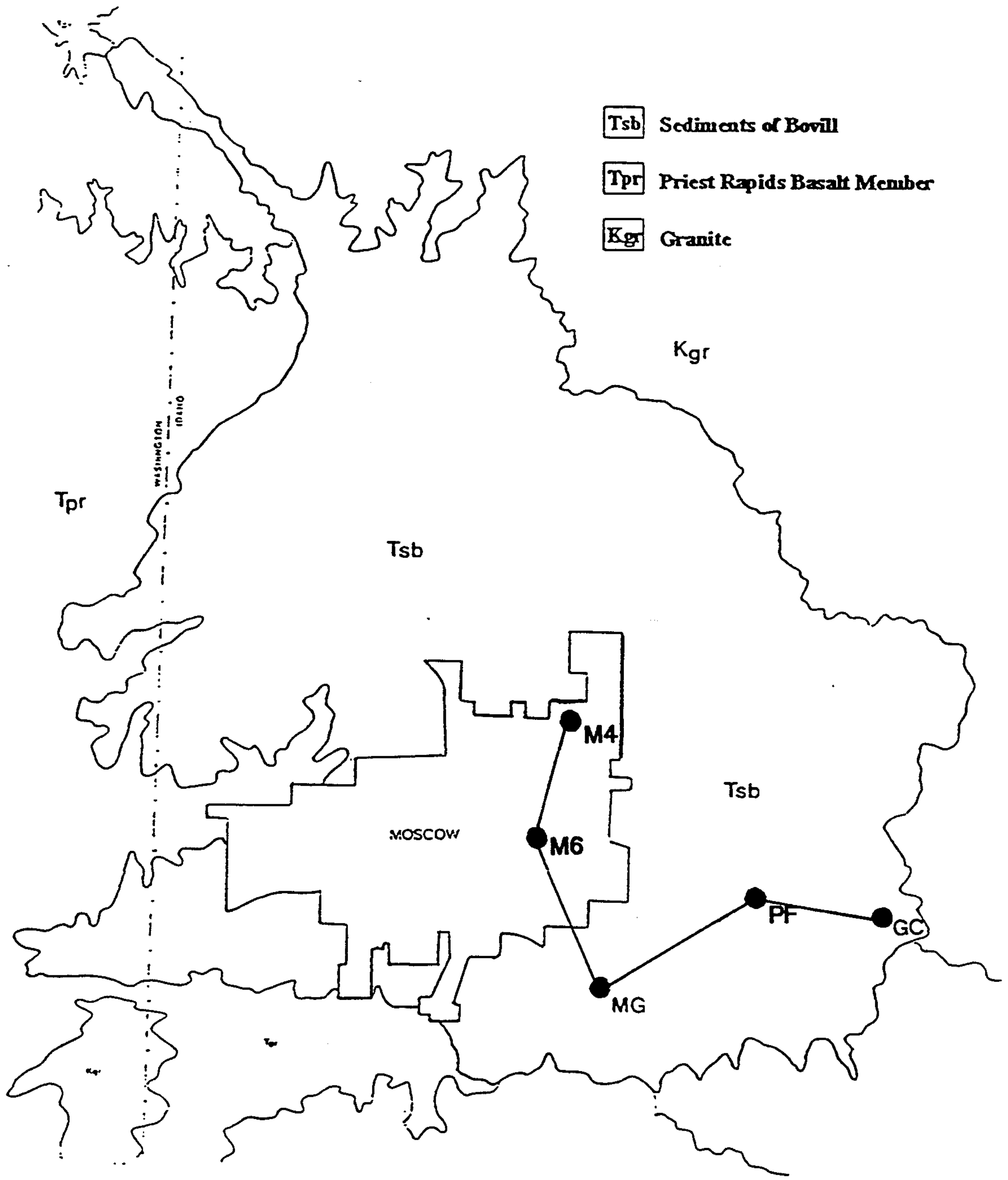


Figure 4. Map view showing the location of Moscow City wells 6 (M6) and 4 (M4), Parker Farm well (PF), Memorial Gardens well (MG) and the Golf Course well (GC).

eastern most well, Elks Golf Course (39N-5W-15adc), shows the thickness of the Priest Rapids at 35 meters (114 feet). Lithologic descriptions, thicknesses and depths of each well are presented in Appendix A.

The well data indicate a relatively uniform thickness of the Priest Rapids Member throughout the western side of the study area; however, well data east of the Parker Farm well, (Elks Golf Course 39N-5W-15adc) indicates thinning and pinching out of the basalt flow.

Wells completed in sections 10 and 3 of the Moscow East quadrangle (Plate 1) do not show the presence of basalt and record up to 91 meters (298 feet) of sediment. This lack of basalt indicates the Priest Rapids Member thins laterally and pinches out towards the granitic margin. Figure 5 is a fence diagram illustrating the thinning nature of the Priest Rapids Member towards the granitic margin.

Saddle Mountains Formation

Flows of the Saddle Mountains Formation, which include the Weissenfels and Onaway Members, occur in the Moscow area. Flows of the Weissenfels Member (Twr) were first noted north of Moscow by Hooper and Webster (1982). Basalt flows of the younger Onaway Member (Ton) were noted on the adjoining Troy Quadrangle (Bush and Priebe, 1995). Both of these flows are localized and do not have any significant lateral extent.

In the Moscow area, the Weissenfels Member (Twr) consists of the basalt of

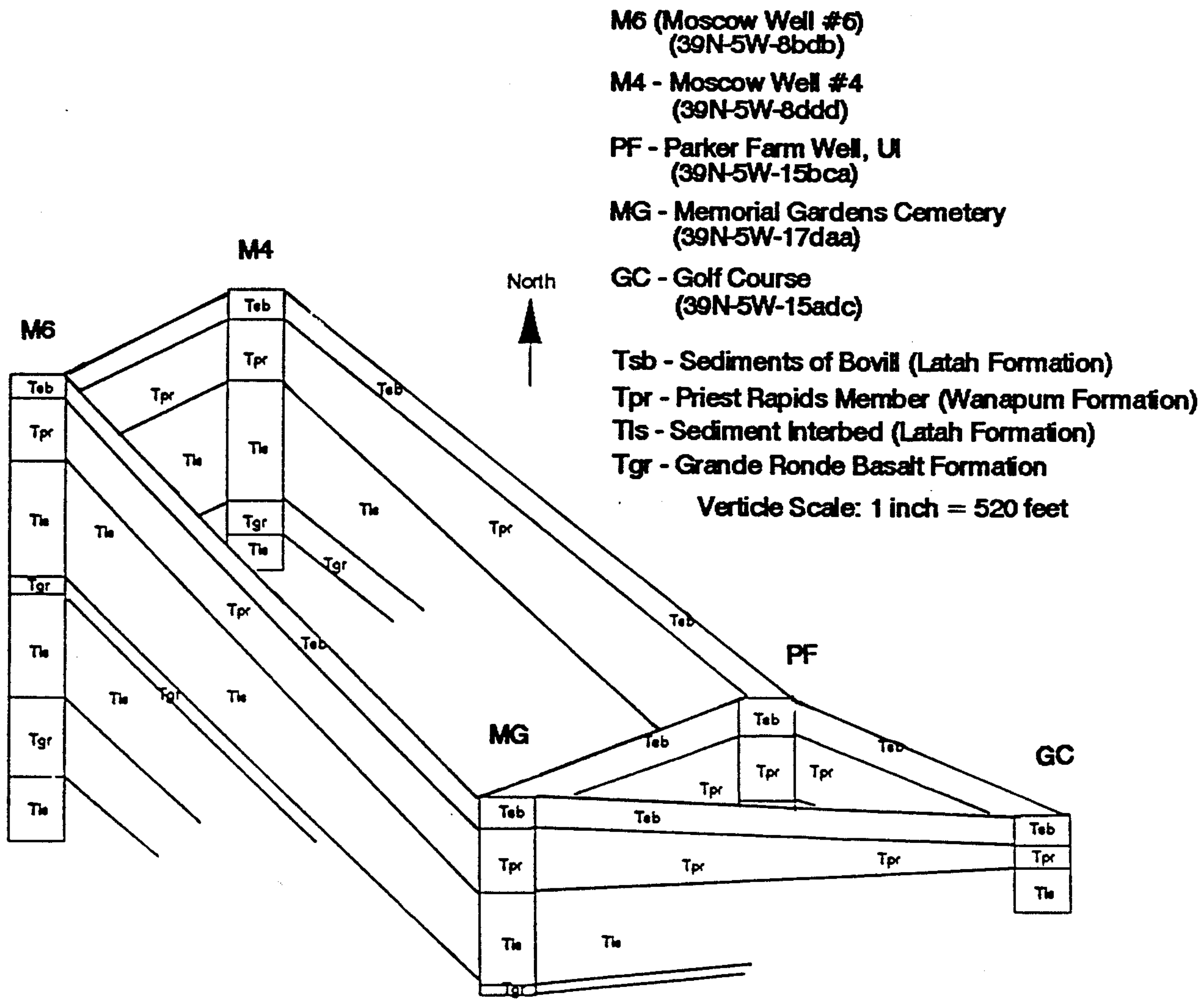


Figure 5. Fence diagram illustrating the lateral continuity of the Wanapum Basalt (Tpr) and the sediments of Bovill (Tsb) in the eastern portion of the Moscow-Pullman basin (Well locations shown on Figure 4).

Lewiston Orchards. These units are medium to coarse-grained, with microphenocryst of plagioclase and olivine in a intergranular matrix with minor glass (Camp, 1976, Hooper and others, 1985). Higher concentrations of Al_2O_3 and CaO distinguish these flows from the Priest Rapids Member of the Wanapum Formation. The basalt of Lewiston Orchards occurs as an isolated outcrop in the central-eastern portion of the Moscow East quadrangle (Plate 1). This flow overlies the Priest Rapids Member (Tpr) of the Wanapum Formation.

The Onaway Member (Ton) is the youngest basalt unit in Latah County. These flows contain large plagioclase phenocrysts (10mm) in a dense groundmass, and are higher in TiO_2 (>3.5%) than most Columbia River Basalt flows and generally have a normal magnetic polarity (Bush and others, 1995a). The Priest Rapid flows of the Wanapum Formation have higher SiO_2, lower K_2O, common olivine phenocryts, and reverse magnetic polarities.

Exposures of Onaway flows are found above the Priest Rapids Member of the Wanapum Formation throughout Latah County with one exposure observed in the extreme north-central part of the Robinson Lake quadrangle (Plate 2). This basalt flow fills a valley in older Precambrian rocks. Elevation of this flow is about 896 meters (2900 feet) above sea level which correlates with field observations of typical inter-canyon Onaway flows at other localities in Latah County. These basalts are interpreted to belong to the Saddle Mountains Formation (Bush and others, 1995a) rather than representing the top of the Wanapum Formation which was proposed by Camp (1981).

Thicknesses and relations between the Saddle Mountains, Wanapum and the underlying Grande Ronde formations, within the study area suggest that before these invading flows, the Moscow area was a steep canyon eroded into crystalline rocks. Flows beginning with the Imnaha Basalt Formation filled valleys into the western end of the basin preceded by periods of erosion and sediment deposition. Continued eruptions and periods of sedimentation began to fill the ancestral basin and study area. This infilling resulted in sequences of basalt flows and interbedded sediments in the eastern end of the Moscow-Pullman basin.

Latah Formation

The Latah Formation (Tls) consists of unconsolidated clay, silt, sand and gravel sediments that are associated with the Columbia River Basalt flows. In the study area, the Latah Formation is found beneath, between, above and laterally equivalent to individual basalt flows. Latah Formation sediments also rest on top of the upper most basalt flow of the Wanapum Formation (Figure 6). This upper most sequence is informally referred to as the sediments of Bovill because of the general "non-interbedded" nature with respect to the basalt flows. There are numerous deposits similar to the sediments of Bovill in composition and origin throughout Latah County.

The Latah Formation includes various interbeds within the study area. Sediments between the Wanapum and the upper most flow of the Grande Ronde

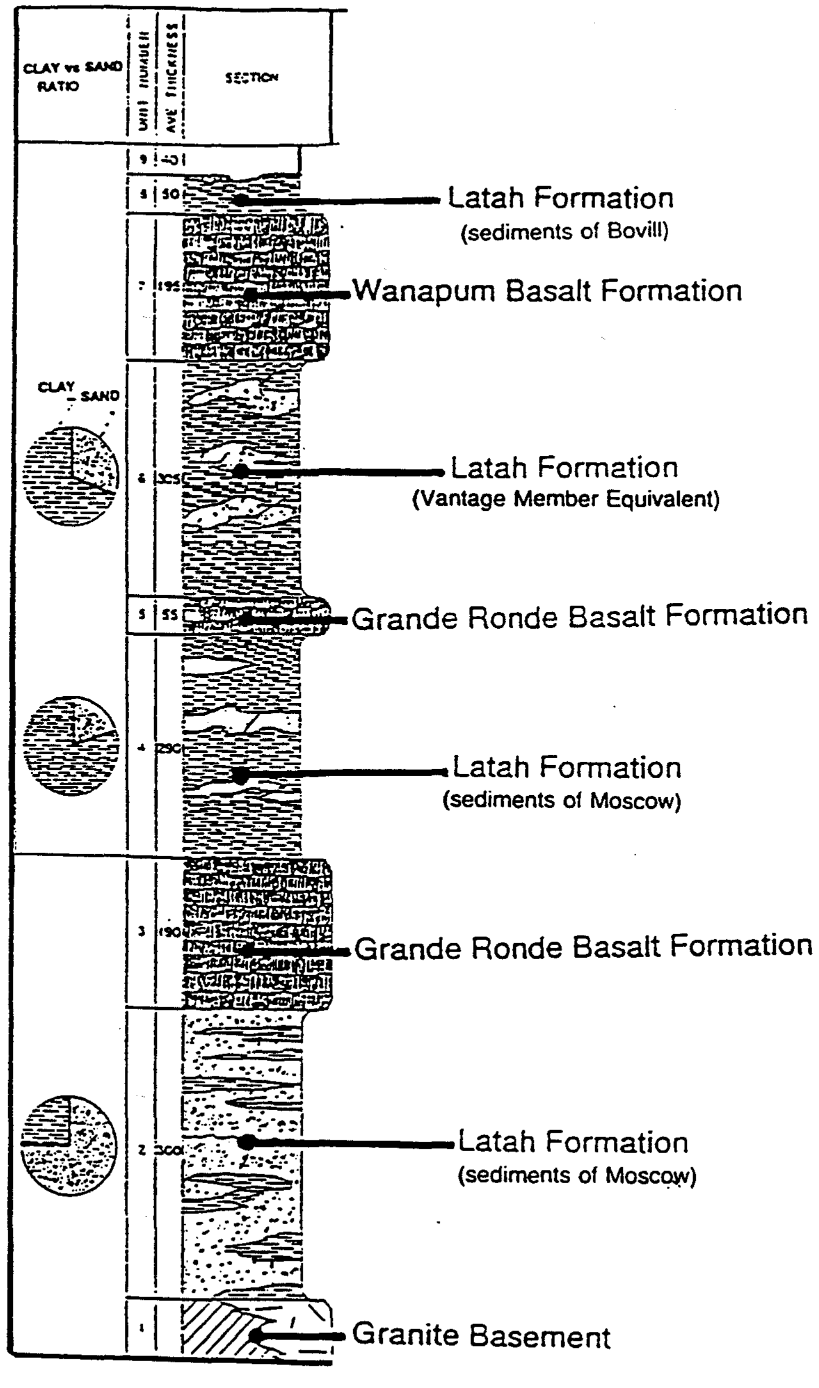


Figure 6. Stratigraphic section from Moscow well 6 (39N-5W-8bdb) showing Basement material, Grande Ronde Basalt Formation, Wanapum Basalt Formation and the Latah Formation above, between and below both basalt formations. Modified from Cavin (1964).

Formation are correlated with the Vantage Member (Siems and others, 1974). Sediments beneath and interbedded with the Grande Ronde are informally referred to as the sediments of Moscow (Bush, Personal communication, 1996). In general the term Latah interbeds refer to any of the Latah units that separate basalt flows. Figure 6 illustrates the suggested stratigraphic nomenclature for the Columbia River Basalts and Latah Formation for the Moscow-Pullman basin.

Pardee and Bryan (1926) present the earliest descriptions of the Latah Formation. Kirkham and Johnson (1929), Scheid (1946) and Hosterman and others (1960) extend and redefine the Latah Formation observing the interbedded relations between the basalt flows. Bond (1963) describes various interbeds in association with basalt flows in the Clearwater embayment located in central-west Idaho just south of the study area. The Latah Formation in the Moscow area is previously mapped by Hubbard (1956) and Lin (1967).

This section focuses on; 1) the composition and grain size distribution; 2) map and subsurface distribution and; 3) the depositional environments characterizing the Latah interbeds and the sediments of Bovill, which are both present in the study area.

Composition and Grain Size Distribution

The Latah interbeds are generally composed of clay, silt, sand and gravel of various sizes and compositions. Cavin (1964) presents a detailed grain size and composition analysis, based on the study of Moscow City well 6 (39N-5W-8bdb).

This study resulted in a generalized stratigraphic section which shows the grain size distribution and compositional characteristics of Latah interbeds which Cavin (1964) labeled from base upwards, units two, four and six (Figure 6). Latah interbed (Vantage Member) or unit six is composed of 25 percent silt and arkosic sand size grains with clay comprising up to 75 percent (Cavin, 1964). Latah interbed (upper most sediments of Moscow) or unit 4 underlying the Grande Ronde Basalt (unit 5 on figure 6) contains approximately 25 percent clay with dominant arkosic sand and silt fractions. The clay to sand ratio reported for this interbed was 15-25% sand (Cavin, 1964). Latah Interbed (lower most sediments of Moscow) or unit two contains chiefly arkosic sand with minor amounts of silt and quartz sand. The sand ratio here ranges from 60 to 75% sand (Cavin, 1964).

Distribution and Occurrence

Moscow city wells 6 (39N-5W-8bdb) and 4 (39N-5W-8ddd), Parker Farm well (39-5W-15bca), Sunset Memorial Gardens well (39-5W-17daa) and the Golf Course well (39-5W-15adc) show the subsurface distribution and the occurrence of Latah interbeds within the study area. Figure 4 shows the location of each well within the study area. These individual well logs (presented in appendix A) show the nature of the interbedded sediments overlying and underlying the basalt flows, which can be correlated to illustrate the change in thickness and lateral extent.

Latah interbed one (Vantage Member equivalent, Tls) represented in the fence diagram in Figure 5 thickens to the east towards the margin of the study area. Thickness of this interbed underlying the Wanapum Formation is 107 meters (350 feet) in Moscow City well 6, 102 meters (334 feet) in Moscow City well 4 and thickens to at least 110 meters (360 feet) to the east from the Sunset Memorial Garden well to the Elk's Golf Course well (the eastern most well). Data regarding the thicknesses and lateral extent of the upper and lower sediments of Moscow are limited. These units are only observed in Moscow City well 6 (39N-5W-8bdb) and lateral extent to the east must be estimated; however, considering the emplacement of basalt flows from the west, the lower sediments of Moscow must be continuous to the east and in contact with the crystalline rocks.

South of the study area along the southern flanks of Paradise Ridge, well data are sparse but available information indicates that the sediments are very thin overlying the Wanapum Formation. From well data, sediments are interpreted to occur from 1.5 to 3 meters (5 to 10 feet) in thickness over the top of the Wanapum Formation. Plate 1 illustrates a cross-section through the study area and a portion south of Paradise Ridge. From the cross-section, a very thin layer of sediment is evident off the flanks of Paradise Ridge. Thin sediment accumulation probably resulted from small narrow drainages along the southern flanks of Paradise Ridge.

Deposition

Bond (1963) states that in the area south of the Moscow East quadrangle the Latah Formation can be divided into three interbed types; deformational, composite and marginal. The deformational type is characterized by simultaneous deposition of sediments and volcanic material. The composite type sediment is characterized by basement detritus in one area of the interbed and basalt detritus deposited elsewhere in the interbed. In the marginal type, the interbeds are situated near the basalt-basement contact and are produced from the ponding of ancestral rivers and creeks by the lava flows and the deposition of stream load in stilled waters (Bond, 1963).

The marginal interbed type is defined below by six characteristics.

1. The Latah Formation in places rests upon the upper most basalt flow (sediments of Bovill) between flows and upon the basement complex.
2. The Latah Formation is composed of basement and metamorphic detritus with minor amounts of ash and basalt fragments probably carried to the margins across the plateau. Minor amounts of organic matter are present from vegetated growth on basement slopes and in ponded waters.
3. The sediments of Bovill in the study area are exposed in some places as cross-bedded sand and gravel interbedded with clay and silt.
4. The silts and clay units show fine laminations and massive bedding.
5. The longer the time lapse between active basalt flows, the greater is the accumulation of sediment.
6. The areas of thicker deposits are closer to the margin (granitic basement) and become thinner away from the margin.

The Latah interbeds within the study area clearly indicate a marginal type interbed network. The range of compositions and grain size distributions suggest the Latah interbeds are the result of fluvial and in places lacustrine environments. The sediments resulted from overfed streams where stream gradients were drastically changed by the invading basalt flows from the west. Grain size distribution and the composition of the Latah interbeds from Cavin's (1964) studies indicate that the sediment was transported short distances. In places, these sediments were deposited in quiet waters. However, it must be realized that the composition and grain size distribution were analyzed using data from one well (City of Moscow well 6, 39N-5W-8bdb) and lateral facies changes throughout the study area most likely occur. However, the thickness of coarse sands are significant, because they occur within sequences that are overall upward-fining in nature suggested by field investigations and analysis of well log data.

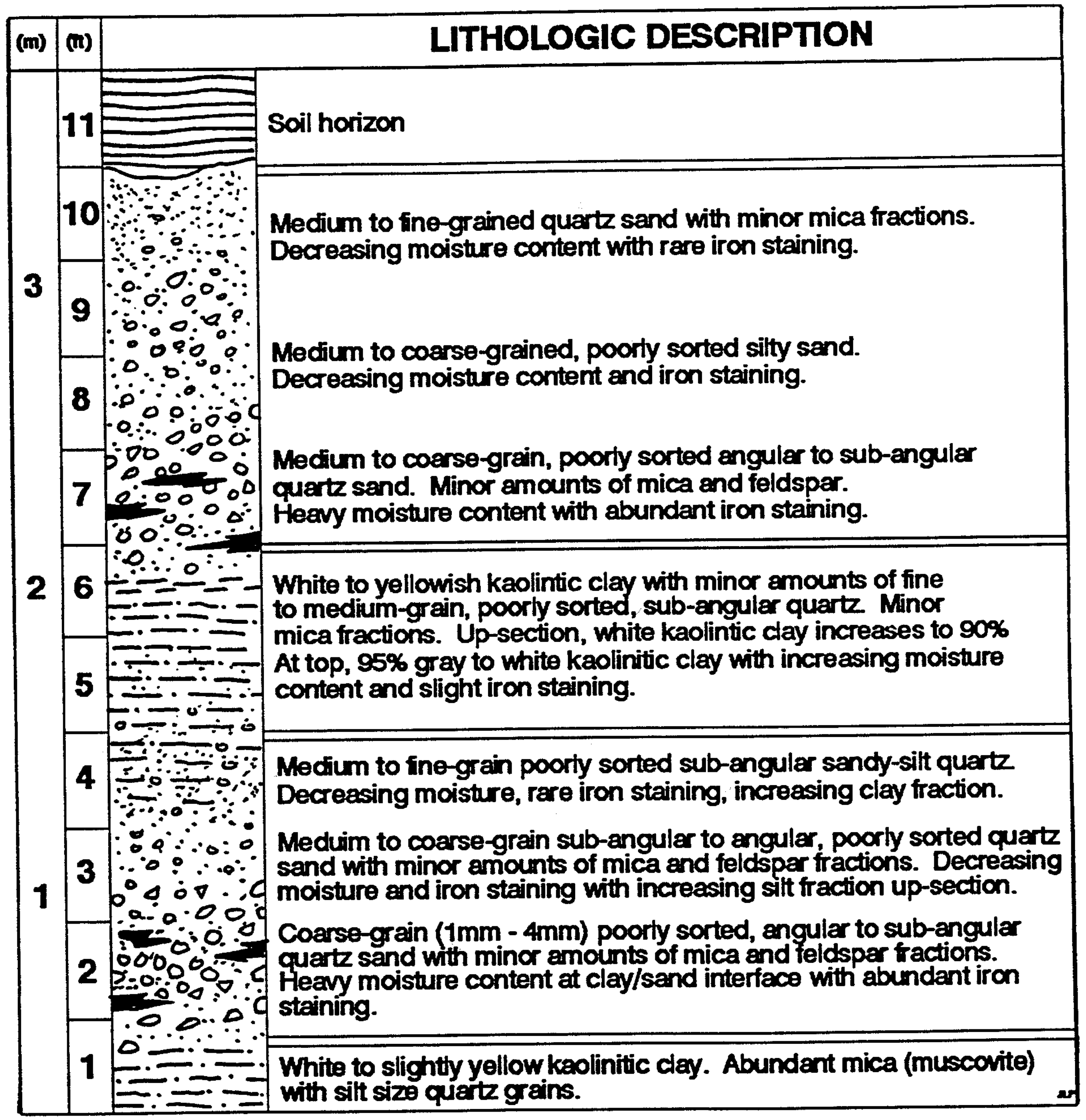
Sediments of Bovill

Composition and Grain Size Distribution

The sediments of Bovill overlie the Priest Rapids Member of the Wanapum Formation, areas of basement rock and grade laterally and vertically into the Palouse loess. The sediments of Bovill are mapped on portions of the Robinson Lake and Moscow East Quadrangles (Plates 1 and 2) and extend into the Viola and Moscow West Quadrangles (Provant, 1995). These sediments are composed largely of clay, silt, sand and gravel originating primarily from metamorphic sources coupled with smaller proportions of basalt and granitic sources. The sediments are dominantly yellow, white to gray high alumina micaceous clays with organic matter common (Cavin, 1964). Outcrops are rare but identifiable in eastern Moscow due to the white color of kaolinite. The sediments of Bovill in the Moscow area were originally referred to as the Canfield-Rogers deposit (Hosterman, 1960). Excavated areas in eastern Moscow show upward fining sequences that range in thickness from .6 meters to 1.5 meters (2 to 5 feet). The sediments are poorly sorted, locally cross-bedded with poorly to moderately rounded quartz gravel at the base which grades upward into fine-grained sand and in turn are overlain by clay, generally kaolinite. Figure 7 represents a measured stratigraphic section showing a portion of the sediments of Bovill. This partial stratigraphic section illustrates cyclical upward fining sequences with kaolinite clay caps. The section was measured in a gravel pit located east of Moscow (39N-5W-9acd1).

Distribution and Occurrence

Distribution and occurrence of the sediments of Bovill in the Moscow area can be interpreted from numerous wells or control points that fully penetrate both the Palouse Formation and sediments of Bovill. The lithologic contact between the Palouse Formation and the sediments of Bovill is interpreted as the first appearance of yellow and white clay and/or the occurrence of a significant sand



LITHOLOGIC DESCRIPTION

Soil horizon

Medium to fine-grained quartz sand with minor mica fractions. Decreasing moisture content with rare iron staining.

Medium to coarse-grained, poorly sorted silty sand. Decreasing moisture content and iron staining.

Medium to coarse-grain, poorly sorted angular to sub-angular quartz sand. Minor amounts of mica and feldspar. Heavy moisture content with abundant iron staining.

White to yellowish kaolintic clay with minor amounts of fine to medium-grain, poorly sorted, sub-angular quartz. Minor mica fractions. Up-section, white kaolintic clay increases to 90% At top, 95% gray to white kaolinitic clay with increasing moisture content and slight iron staining.

Medium to fine-grain poorly sorted sub-angular sandy-silt quartz. Decreasing moisture, rare iron staining, increasing clay fraction.

Meduim to coarse-grain sub-angular to angular, poorly sorted quartz sand with minor amounts of mica and feldspar fractions. Decreasing moisture and iron staining with increasing silt fraction up-section.

Coarse-grain (1mm - 4mm) poorly sorted, angular to sub-angular quartz sand with minor amounts of mica and feldspar fractions. Heavy moisture content at clay/sand interface with abundant iron staining.

White to slightly yellow kaolinitic clay. Abundant mica (muscovite) with silt size quartz grains.

Figure 7. Stratigraphic section delineating a portion of the sediments of Bovill. Section is located at 39N-5W-9acd.

unit. The total thickness and sand/clay percentages were calculated once the contact between the Palouse Formation and the sediments of Bovill was determined. Thicknesses and distribution is illustrated by an isopach map, represented in Plate 3; the sand-gravel/clay percentages are shown in Plate 4.

The isopach map indicates the sediments of Bovill thicken towards the granitic margin reaching a maximum thickness of 54 meters (300 feet) to the east and thin towards the west, away from the crystalline margin, until they pinch out near the Idaho-Washington boundary. The sediments are thickest within the middle area of the isopach map shown in Plate 3 (approximately 60 meters (200 feet) thick). These thicker areas are typically clay rich, while thinner areas of the deposit are generally composed of sand and gravel. This relationship can be shown by superimposing the isopach map represented in Plate 3 on the sand-gravel/clay percentages illustrated in Plate 4.

Plate 4 illustrates a sand-gravel/clay percentage map that shows the percentage of sand and gravel to the total thickness of the sediments of Bovill deposit. For example, a 100 foot thick deposit that contains a 20 foot cumulative amount of sand/gravel will yield a 20% sand-gravel value. The percentage map shows the amounts of sand and gravel deposits ranging from 85 to 100 percent near the granitic margin. Comparison of sand and gravel distribution to the topographic relief show high concentrations of coarse sediment occurring within topographic lows or stream drainages. This correlation is evident in both the Palouse and Paradise stream drainages (Plates 1 and 4), indicating that much of present topography is controlled by lithofacies changes within the sediments of Bovill. Areas of high unconsolidated sand and gravel deposits are less resistant to stream erosion while areas of clay are more resistant and form many of the hills in Moscow. In other words, the present streams follow roughly the same locations as the ancestral streams.

The distribution of coarse sand and gravel govern the location and direction of stream channels within the study area. Plate 1 shows the Palouse South Fork River drainage along the margin of the crystalline basement rocks. Paradise Creek drainage parallels the Palouse drainage. The direction of both drainage systems are primarily controlled by the high percentage of unconsolidated sand and gravel deposits.

As both streams continue to erode and incise downward through the sediments of Bovill, the streams will eventually make contact with the underlying basalt. At this point, its possible that stream direction will begin to change into a north-westerly direction which is common for many stream channels in basalt throughout western Latah County and Whitman County.

Deposition

The sediments of Bovill are interpreted to have formed from a series of sediment saturated or clogged streams producing the deposition of quartz sand and gravel. The finer clay and silt deposits may represent overbank deposits. The fluvial origin is indicated by the presence of upward fining sequences of sediments found both in the field and encountered in well logs. Lakes, ponds, and swampy areas must have been also present on the fluvial plains. These conclusions suggest a continuation of the marginal type sediment deposition, which is also noted for the older Vantage Member and the sediments of Moscow.

Palouse Formation

The Palouse Formation covers bedrock over much of eastern Washington and the northern part of Idaho. This formation was deposited during the Pleistocene epoch as determined by the identification of mammal bones (Frywell, 1962a). Numerous road cuts provide excellent age relations from layered tephra deposits and have allowed the investigation of the composition and origin (Baker, 1991). This section focuses on the composition, distribution and origin of the Palouse Formation within the study area.

The composition and description of eastern paleosol horizons have been described by numerous workers. Treashers, (1925), Bryan, (1927), Rieger, (1952), McGeery (1954) and Krapf (1978) provide reports identifying primary and secondary minerals observed within the Palouse Formation. Primary minerals are quartz, feldspar, hornblende and mica. Secondary minerals are altered mica, pyroxenes, opaque minerals, epidote and zircon. Both primary and secondary minerals comprise major paleosols throughout the formation.

Four major paleosol horizons are distributed throughout the formation (Krapf, 1978). Albic, argillic, cambic and fragipan horizons dominate throughout the deposit defining the heterogeneity nature and range of compositions. Paleosol stratigraphy and geomorphic features within the Palouse Formation give rise to the origin of the present day rolling hill topography.

Alluvium and Colluvium

Alluvium and colluvium deposits within the study area are predominately stream and slope-wash material deposited during the Holocene epoch. Composition of the sediments are variable, and commonly composed of reworked loess or mixtures of loess, basalt and granitoid fragments. Exposures are primarily restricted to stream valleys throughout both quadrangles (Plates 1 and 2). These sediments exist, as wide map patterns on plates 1 and 2 representing stream and slope wash depositional environments of Paradise Creek and the South Fork Palouse River.

HYDROGEOLOGY

Introduction

Decreasing water levels in the upper and lower aquifers in the Moscow-Pullman basin have created increasing concern with respect to future groundwater supplies. The detailed geology, hydrogeology and mechanisms of recharge to the basin must be known in order to implement a suitable groundwater management plan for the entire basin. This section describes the hydrological aspects of the shallow sediments and the top of the underlying Wanapum Formation. The hydrological aspects include: 1) hydrologic setting; 2) hydrologic characteristics; 3) groundwater flow characteristics and 4) evaluation of recharge potential.

Hydrologic Setting

Kopp (1994) outlines three major hydrostratigraphic units that contribute groundwater to domestic and municipal uses throughout the basin and study area. These are: 1) the shallow sediments and upper Wanapum Formation; 2) Wanapum formation with associated Latah Formation interbeds and 3) Grande Ronde Formation with associated interbeds of the Latah Formation. Figure 8 illustrates the hydrostratigraphic units in the study area using lithologic data presented in Moscow well 6 (39N-5W-8bdb). The shallow aquifer consists of alluvium, loess deposits, sediments of Bovill and the flow top of the Priest Rapids Member of the Wanapum Formation. The upper aquifer is defined from the

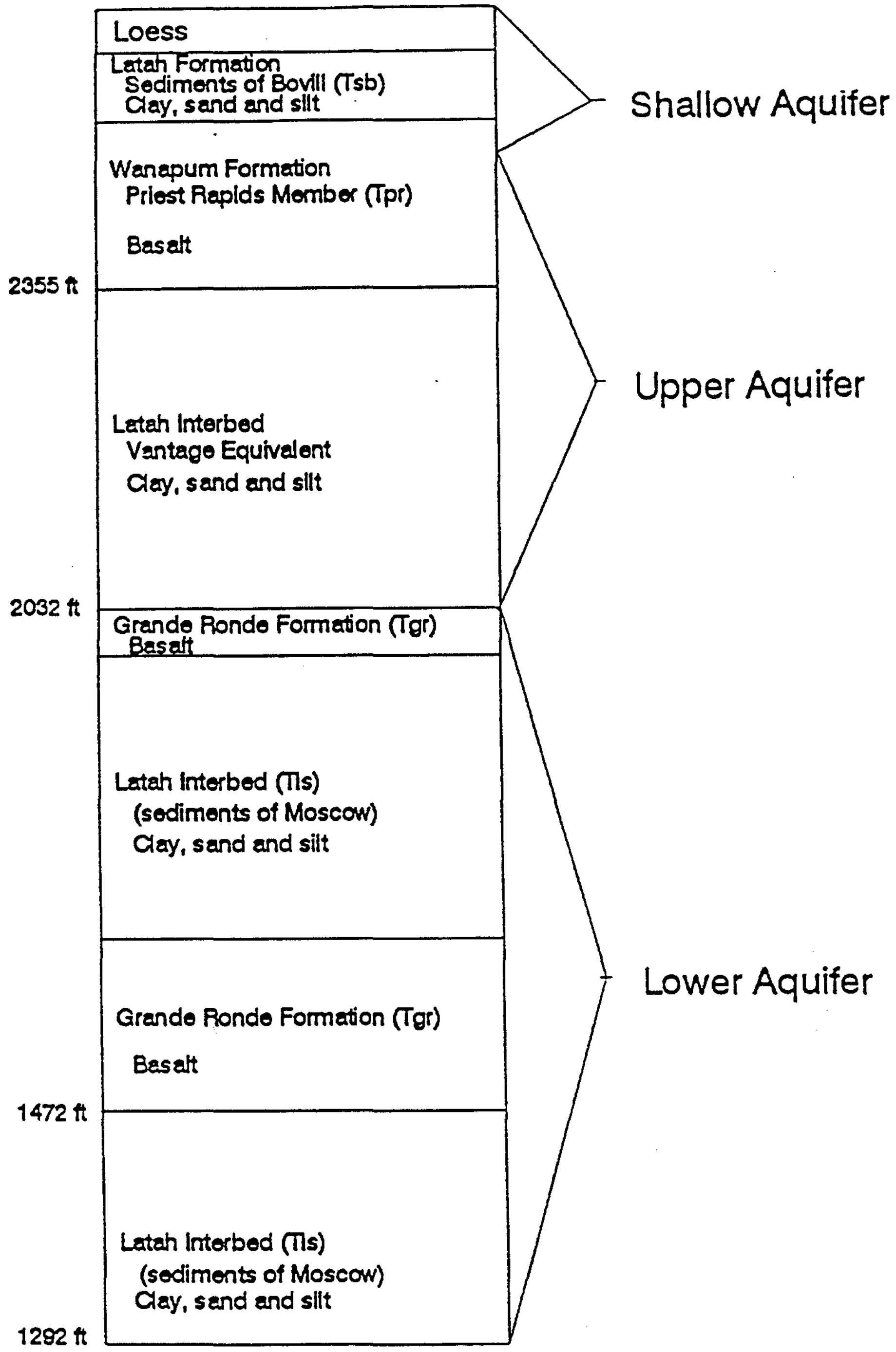


Figure 8. Hydrostratigraphic units shown from Moscow City Well 6 (39N-5W-8bdb) and lithologic units making up each aquifer system.

middle portion of the Wanapum Formation and the first Latah interbed (Vantage equivalent). The lower aquifer is characterized by the Grande Ronde Formation and the associated interbeds referred to as the sediments of Moscow. This report is only concerned with the hydrological aspects regarding the shallow sediments and the upper contact of the Priest Rapids basalt.

Hydrologic Characteristics

Hydrologic characteristics defining the shallow sediments are governed by the distribution and occurrence of detritus material making up each unit. The loess deposits consist primarily of silty clay whereas the sediments of Bovill are characterized by coarse sand-gravel with some clay near the margin and clay with lesser sand and gravel located away from the margin. Hydrologic characteristics defining the top of the Wanapum Basalt (Priest Rapids Member) are governed by the nature of the flow top.

A groundwater flow model presented by Lum and others (1990) simplifies the hydrologic characteristics in the study area by combining alluvium, sediments of Bovill and loess deposits. However, there are distinct lithological and hydrological differences between these units. These differences result in differing vertical and horizontal hydraulic conductivity values for each unit and alter the previous recharge numbers implemented in the groundwater flow model presented by Lum and others (1990).

Loess Deposits

Hydraulic conductivity values by Lum and others (1990) for the Palouse loess represent the occurrence of clayey layers. The high clay content in the loess decreases the typical vertical and horizontal hydraulic conductivity; however Baker and others (1991) suggest that groundwater movement is enhanced by structural features such as plant roots and animal burrows. For groundwater modeling purposes, Lum and others (1990) estimate the horizontal hydraulic conductivity for the Palouse loess at 1.5 m/d (5 ft/d) and assume that the loess is the dominant lithology within the study area. This value is based on long term infiltration rates calculated by Williams and Allman (1969), and horizontal conductivity values from Freeze and Cherry (1979).

Field and well log data show that the loess increases in thickness to the west and thins to the east towards the margin. Therefore, infiltration to the groundwater system in the western portion of the study area may be dominated by the vertical and horizontal hydraulic conductivity values suggested by Lum and others (1990). However, infiltration to the east towards the margin is dominated by the vertical and horizontal hydraulic conductivity values characteristic of the sediments of Bovill.

Sediments of Bovill

Hydrologic characteristics regarding the sediments of Bovill are poorly understood. The heterogenous nature of this unit needs further hydrological investigation to accurately quantify vertical and horizontal hydraulic conductivities. Hydraulic conductivity can be estimated based on lithologic data from domestic well logs and data given by Hosterman and others (1960), where they present an investigation of the Canfield-Rogers clay deposit (sediments of Bovill).

Field relations show coarse-grained graded bedding that fine upwards to laminated clay layers. Hydraulic conductivity can be estimated by observing the horizontal hydraulic conductivity values presented for each type of sediment layer (Table 2). Roughly horizontal layers of finer grained sediments control the infiltration rates. The highest vertical hydraulic conductivity values probably occur along the east margin of the Sediments of Bovill. The hydraulic conductivity values probably are in the sandy silt range.

Table 2. Horizontal Saturated Hydraulic Conductivity values representing sedimentary units in the sediments of Bovill.

Freeze and Cherry, 1979		Domenico and Schwartz, 1990	
Sediment	**K values (ft/d)**	**Sediment**	**K values (ft/d)**
Clay (Aquitard)	.0000002 - 002	Clay (Aquitard)	.000008 - .08
Sandy-Silt	.30 - 30	Sandy-Silt	.50 - 5
Coarse-gr Sand	30 - 300	Coarse-gr Sand	.20 - 1600
Coarse-gr Sand and Pebble-sized Gravel	300 - 3000	Coarse-gr Sand and Pebble-sized Gravel	2 - 1600
Pebble-sized Gravel	300 - 3000	Pebble-sized Gravel	80 - 8600

Upper Contact of the Wanapum Formation

Basalt flows display various types of joint and fracture patterns as each flow cools and solidifies from a molten state under static conditions. A flow top and three major zones with unique sets of joints are commonly observed and characterizes a typical Columbia River Basalt flow (Figure 9). At flow tops, vesicular regions are common creating scoreaceous textures which may give rise to areas of high permeability. Weathering of the flow top and sediments covering the weathered surface control hydraulic conductivity of the flow top zone.

Groundwater Flow Characteristics

This section focuses on groundwater flow characteristics within the sediments of Bovill and the flow top of the Priest Rapids Member. Groundwater flow characteristics within the sediments of Bovill and top of the Priest Rapids Member are principally governed by the lithology and geologic structure.

Sediments of Bovill

Groundwater moves primarily through coarse sand layers that are predominately found in paleo-stream channel areas where sand-gravel percentages are high. Clay zones have lower hydraulic conductivity values. These clay layers inhibit vertical and horizontal flow; Most groundwater flow occurs along preferential pathways represented by coarse sands and gravel.

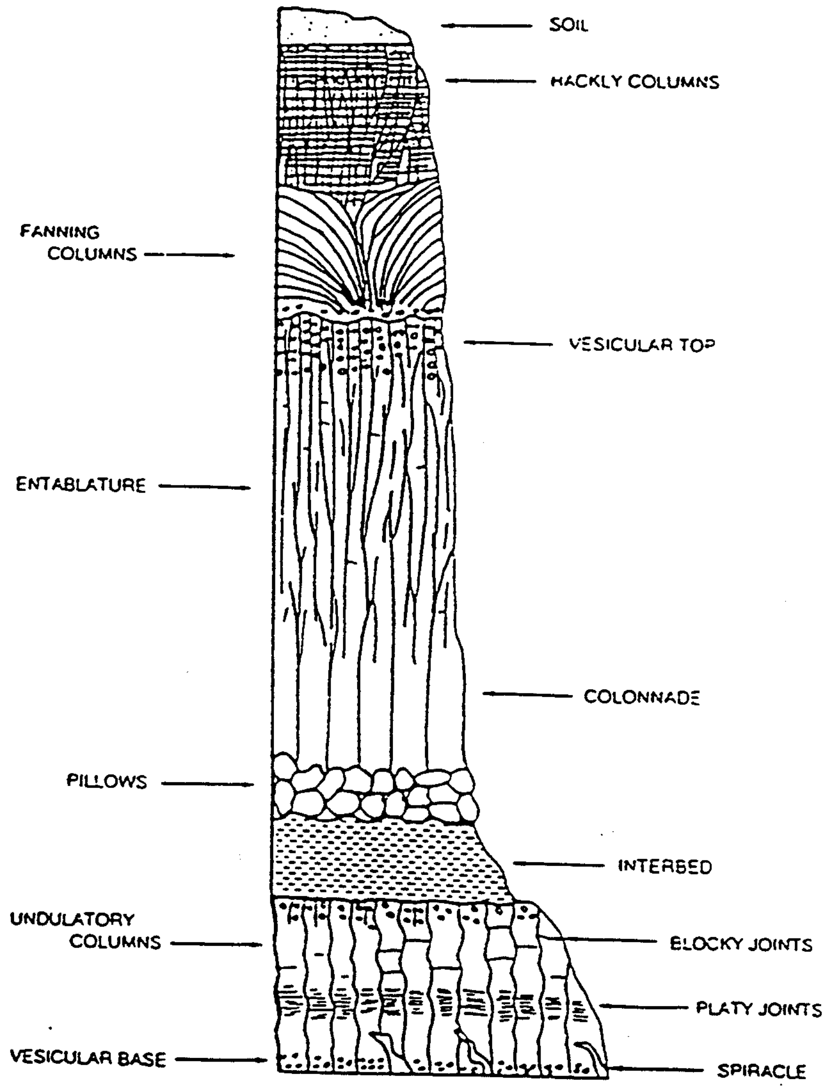


Figure 9. Physical characteristics of Columbia River Basalt flows. After Bush (1992).

Where there is a break in the lateral continuity of the clay layers, groundwater probably migrates both vertically and horizontally through higher hydraulic conductivity material.

Evaluation of Groundwater Levels

Analysis of Well Development

Water levels in 41 domestic wells were measured. These domestic wells partially or fully penetrate portions of the Wanapum Formation. None of the wells are completed in the sediments overlying the basalt. Table 3 shows the location, owner (registered on well log), elevation of well, static water level, depth to the top of the basalt, depth completed in the basalt, previous water levels measured and water levels last measured. Plates 1 and 2 show the location of each well which is indicated by the well number in table 3. Water level measurements for each well were conducted between the months of September through December of 1994 using the electric tape method.

Previous water level measurements for these wells were completed in the 1970's and 1980's and comprise 34% and 31% respectively of the total number of well logs. Wells completed and inventoried in the 1950's, 1960's and the 1990's comprise 2%, 14% and 17% respectively of the total number of well logs. A few wells listed in Table 3 give the owner and previous water level measurement, but were unmeasurable in this study and are indicated with a dash. In the month of January 1995, follow up measurements in ten wells were

Table 3. Moscow East Quadrangle well level data (Study Area)

Well #	T39N 5W Section	Owner on Log	Yr. Drilled	L.S. Elev. (ft)	W.L. Reported When Drilld (ft)	Measurement (ft)	Date	Last Measurement (ft)	Date	Depth to Basalt (ft)	Depth comp. in Basalt (ft)	*Comp zone
1	4ab	B. Lewandowsk	1993	2625	145			150.1	9-94	168	185	L
2	4bb	J. Hunter	1993	2620	158			155.4	9-94	183	20	U
3	4ccb1	J. Parks	1968	2655 R	69	49.9 R	1-72	57.3	9-94	114	56	M
4	4ccd2	H. Carleton	1952	2665 R	175	170 R	11-53	182.0	9-94	159	61	M
5	4cdc2	F. Trail	1969	2628 R	140	131.9 R	7-72 R	136.1	9-94	125	63	M
6	4db	G. Remington *	1983	2620	125	120.9	9-94	121.2	1-95	91	79	M
7	4dd	G. Owen **	1988	2600	119	124.8	9-94	124.0	1-95	111	72	M
8	5a	H. Williames	1988	2640	190			195.3	9-94	183	45	U
9	5ab	E. Burroes	1987	2680	154			157.2	10-94	212	16	U
10	5ac	K. Hungerford	1987	2700	210			214.9	9-94	196	82	M
11	5bc	T. Womak	1993	2640	160			161.4	10-94	160	173	L
12	5bdc1	G. Rich	1969	2627 R	110	121.4 R	6-72 R	126.2	10-94	96	76	M
13	5c	J. Colbert	1988	2680	170			174.1	10-94	175	28	U
14	5c	E. Stalnaker	1991	2600	92			95.7	10-94	61	168	L
15	5cb	J. Mcoy	1982	2640	145			150.1	10-94	126	39	U
16	5cb	W. Largent	1976	2600	80			84.3	10-94	95	187	sediment
17	5cc	D. Willson	1992	2640	93			95.8	10-94	57	71	M
18	5cd	L. Hyke	1988	2580	55			58.6	10-94	87	42	U
19	5cd	M. Gray **	1990	2600	90	91.1	9-94	91.2	1-95	56	59	M
20	5db	P. Wicks **	1988	2660	135	140.8	9-94	140.6	1-95	108	71	M
21	5db	D. Loyd	1986	2660	138			141.3	9-94	136	53	M
22	9bab1	A. flack	1969	2624 R	130	120.7 R	7-72 R	131.4	11-94	79	105	M
23	9bba3	J. Bosse **	1967	2632 R	131	129.8	11-94	129.6	195	180	50	U
24	9bca1	L. Scrimsher	1970	2620	125			129.3	11-94	No basalt contact		
25	15bd	S. Hall	1986	2600	100			104.2	11-94	118	166	L
26	15bd	E. Lidstaff	1983	2640	160			163.8	11-94	179	9	U
27	15cbb1	O. Nelson	1970	2600 R	98	104.1 R	6-72 R	100.6	11-94	102	38	U
28	15dbb1	J. Eldridge **	1971	2594 R	68	67.4	11-94	66.6	1-95	86	100	M
29	16aac1	L. Schierman	1971	2636 R	140	134.5 R	1-72	141.3	12-94	122	171	L
30	16cb	P. Albertson **	1978	2600	97	101.2	12-94	101.2	1-95	194	56	M
31	16cd2	W. Burkland	1987	2640	82			-		46	82	M
32	16da	E. Bontadilli	1988	2700	165			169.8	12-94	180	85	M
33	16daa1	R. McAllister	1971	2617 R	117	112.1 R	6-72 R	112.5	12-94	99	147	L
34	16db	D. Dahl	1993	2620	103			104.2	12-94	115	188	L
35	16dcc1	J. Mengelkemp	1972	2580 R	49	51.6	12-94	50.8	1-95	48	127	L
36	16dcd1	O. Law	1971	2591 R	89	102 6 R	6-72 R	105.3	12-94	46	104	M
37	16dd	S. Schaper	1973	2620	108			111.1	12-94	112	79	M
38	16dd	C. Henderson	1976	2615	30			41.2	12-94	95	13	M
39	16ddd1	E. Bingman	1970	2590 R	130			132.1	12-94	70	144	L
40	16ddd2	J. Atkinson	1968	2590 R	90	80.8 R	7-72	82.2	12-94	69	91	M
41	17ddc1	F. Bennett	1972	2598 R	85	51.7 R	7-72	65.9	12-95	138	2	sediment

R – Reported well data

* U– Upper zone, M– Middle zone, L– Lower zone (All completed in the Wanapum Formation)

** Wells that have been remeasured

completed after a period of high precipitation in the months of November, December 1994 and a portion of January 1995. These measurements are also shown in Table 3.

Comparison of long term water level changes between the months of September, October, November and December of 1994 and from the years 1953, 1955, 1964, 1972 and static water levels of wells completed in 1980 and 1990 indicate varying water level trends throughout the study area. Data analyzed from Table 3 indicate an average water level decline of .4 ft/yr in 75% of wells. Ignoring the one year (1993-1994) data, the range in average annual water level decline is -1.2 ft/yr to .5 ft/yr. Provant (1995) reports larger values of water level decline west of the study area (Moscow West quadrangle). The difference of water levels from Provant (1995) and the study area might be due to the response of recharge delivered to the areas west (less response to recharge) and east of Moscow (more response to recharge).

Data collected from 10 follow up measurements in January 1995 showed slight increases in water levels in the Priest Rapids Member. Water levels increased between 1/2 to 1 foot in wells located close to the crystalline margin and showed no change in wells west of the margin. The rise in water levels close to the margin in the study area correlates with higher water levels at the marginal zone in the Moscow West quadrangle which was reported by Provant (1995). These higher values reported by Provant (1995) may reflect wells completed in the shallow sediments while this report analyzes wells completed in the upper basalt.

Reasons for water level increase include: 1) Recovering aquifer due to decreased water use from June, July and August; 2) rapid recharge moving through coarse-grained sands, close to the margin and reaching the basalt aquifer; 3) barometric efficiency of basalt or 4) combination of all three.

The lack of rising water-levels in wells west of the margin may suggest; 1) that the deeper regional flow system does not react quickly to recharge events and 2) most recharge may occur through stream valleys and never migrate to wells west of the stream valleys.

Methods of Recharge

This section focuses on two mechanisms of recharge to the study area. The first mechanism describes recharge with regards to infiltration of water over the entire study area. The second mechanism considers recharge to the study area through stream valleys and at the basalt-granite contact. In both cases recharge is primarily from precipitation and snow melt during the winter months.

The nature of recharge, through infiltration processes, is highly dependant on the lithology in which infiltrated water comes in contact. The variable nature of sand-gravel/clay lenses and facies changes within the sediments of Bovill results in more infiltrated water through these "preferential pathways" (sand-gravel lenses). Observing the stratigraphic section in the field (Figure 7), coarse sand layers were saturated after recent rains while impermeable clay layers were dry.

Standing water in many places throughout the sediments of Bovill may indicate the presence of clay resulting in a reduction of potential recharge. In other places, the rate of infiltration is rapid suggesting the presence of coarse sands. In any case, the rate of infiltration over the study area is highly varied and difficult to quantify due to the nature of sediment deposition.

Mechanism two includes recharge to the study area at the basalt-granite contact and through the major stream channels. At the basalt-granite contact, water may seep through fractures and joints in the basement rock and come in contact with sand-gravel lenses described earlier. As in recharge mechanism one, these coarse sands act as preferential pathways routing water to the basalt aquifer. In major stream channels the dominance of coarse sands and gravel should give rise to losing stream systems where water recharges to the underlying groundwater system. Areas of major stream valleys are most likely probable major recharge sites throughout the study area.

Recharge to the study area is most likely the result of both mechanisms. Considering the entire surface area of the study area, mechanism one may be the dominate recharge mechanism. This is particularly true to the west as the loess deposits become more prominent. Near the eastern part of the study area where the sediments of Bovill increase in thickness and the clay content decreases, infiltration of water into the coarse sand "conduits" predominate over typical infiltrational processes described in recharge mechanism one. Figure 10 shows a conceptual representation of potential recharge to the study area.

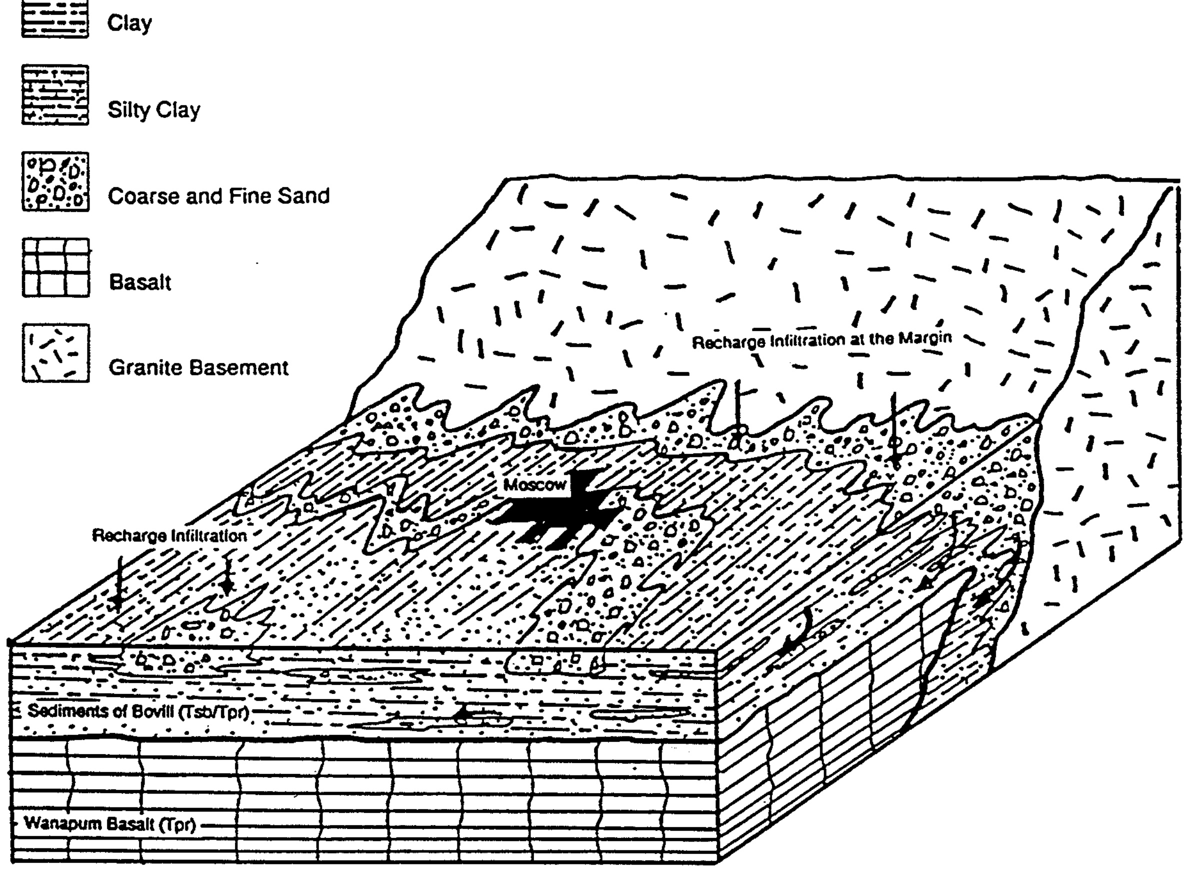


Figure 10. Conceptual stratigraphic model illustrating recharge potential through the basement margin sands, stream valleys and through the clayey areas in the sediments of Bovill.

CONCLUSIONS AND RECOMMENDATIONS

Conclusions

Field studies and the inventory of domestic wells located in the Moscow East and Robinson Lake Quadrangles provide data that describe the composition and distribution of geologic units, water levels, well location and well depth completion. Well logs show additional data that depicts the stratigraphy and hydrostratigraphy of the study area. This study indicates the sediments of Bovill are an important geologic unit which makes up a large portion of the study area. Field study and well data may suggest these sediments are a primary control for recharge in eastern portion of the upper aquifer.

The following describes specific conclusions:

1. Six major geologic units comprise the Moscow East and Robinson Lake quadrangles. These are the Precambrian quartzite, Precambrian quartzite, gneiss and schist, Precambrian-Cretaceous mixed rocks, Cretaceous intrusive rocks, Miocene Columbia River Basalt, Miocene sediments of the Latah Formation and the Pleistocene loess deposits of the Palouse Formation.

2. The sediments of Bovill of the Latah Formation contain various lithologic and depositional characteristics which are distinguishable from the Palouse loess. Therefore, the sediments of Bovill should be regarded as a distinct unit that possesses a unique set of hydrologic and geologic characteristics that differ from the loess deposits.

3. The sediments of Bovill in Moscow represent a deposit characterized by unconsolidated coarse sand and gravel present in stream valleys and topographic highs that are predominately clay rich.

4. A percentage map depicting the sediments of Bovill suggests high concentrations of sand and gravel along the eastern margin of the study area.

5. Groundwater chiefly migrates through the varying coarse sand-gravel lenses, which act as conduits for groundwater recharge responses.

6. Recharge to the study area from infiltration processes through the sediments of Bovill is important in the basin. Recharge may become more dominated by loess hydrologic properties west of the study area towards the central portion of the basin.

7. Major areas of recharge in the study area may be located near major paleo-channels in the sediments of Bovill that have higher hydraulic conductivity characteristics.

8. Rapid recharge may take place along the margin or in major stream valleys as suggested by the rapid water level increase in wells completed in the Priest Rapids Member.

Recommendations

1. Continue to monitor domestic wells in the study area to reflect water level changes and recharge mechanisms to the upper aquifer.

2. Maintain records of drilling logs and lithologic descriptions in order to further define unit contacts on both the Moscow East and Robinson Lake geologic maps.

3. Complete further hydrological investigations to quantify hydrological properties of the sediments of Bovill.

4. Complete detailed studies that investigate groundwater flow characteristics of the sediments of Bovill.

Monitoring changes in water levels and maintaining detailed drilling logs provide investigators hydrological and geological understanding of the study area, specifically characteristics of the Sediments of Bovill. Further hydrological studies of the sediments of Bovill will allow investigators a clearer understanding of the nature of recharge into the eastern section of the Moscow-Pullman basin.

APPENDIX A

The following well descriptions have been compiled from data presented by Crosthwaite (1975). Lithologic descriptions depict the upwards-finning nature of sand to clay "packages" throughout each section.

Moscow Well #4 (39N-5W-ddd)

Lithologic Description	Thickness (feet)	Depth (feet)
Dirt	4	4
Clay	6	10
Gravel/sand	10	20
Gravel	1	21
Clay, yellow	34	55
Clay, brown	5	60
Clay, black	15	75
Basalt	**183**	**258**
Clay/sand	337	595
Basalt	**100**	**695**
Gravel/sand/clay	95	790

Moscow Well #6 (39N-5W-8bdb)

Top soil/clay	17	17
Gravel/clay	4	21
Clay	34	55
Clay/wood	15	70
Basalt	**175**	**245**
Clay/sandy	35	280
Sand	20	300
Clay/sandy	13	313
Clay	4	317
Sand cemented	3	320
Clay/sandy	50	370
Sand	2	372
Clay	35	412
Clay/granite sand	18	430
Granite sand	15	445
Clay	105	550
Sand/Clay	18	568
Basalt	**47**	**615**
Clay	30	645
Shale	142	787
Quartz sand	11	798
Shale	8	806
Cemented sand	10	816
Shale	90	906
Basalt	**222**	**1128**
Quartz sand	41	1169
Shale/fine sand	90	1263
Quartz sand	45	1308

APPENDIX A

Elk's Golf Course (39N-5W-15adc)

Lithologic Description	Thickness (feet)	Depth (feet)
Topsoil	2	2
Clay	10	12
Clay, fine sand	28	40
Clay, sand	5	45
Clay	6	51
Basalt	**94**	**145**
Clay	6	151
Basalt	**17**	**168**
Clay	32	200
Sandy clay	54	254
Sandy clay, water	16	270

Parker Farm (39N-5W-15bca)

Palouse silt loam	20	20
Sand coarse	10	30
Sandy clay	40	70
Clay	10	80
Silty clay	25	105
Basalt	**178**	**283**
Clay	42	325
Sand, argillaceous	35	360
Silty clay	30	390
Clay	20	410
Sand, argillaceous	10	420
Clay, sand	50	470
Sand, coarse	10	480
Clay, sandy	8	488
Quartzite	4	492

Backfilled and cement plug set at 278 feet

Sunset Memorial Gardens (39N-5W-17daa)

Topsoil	5	5
Clay	16	21
Clay, small gravel	18	39
Coarse gravel, water	14	53
Clay	34	87
Basalt	**185**	**272**
Clay	178	450
Granite sand	66	516
Clay	37	553
Basalt	**2**	**555**

Well backfilled to 508 feet

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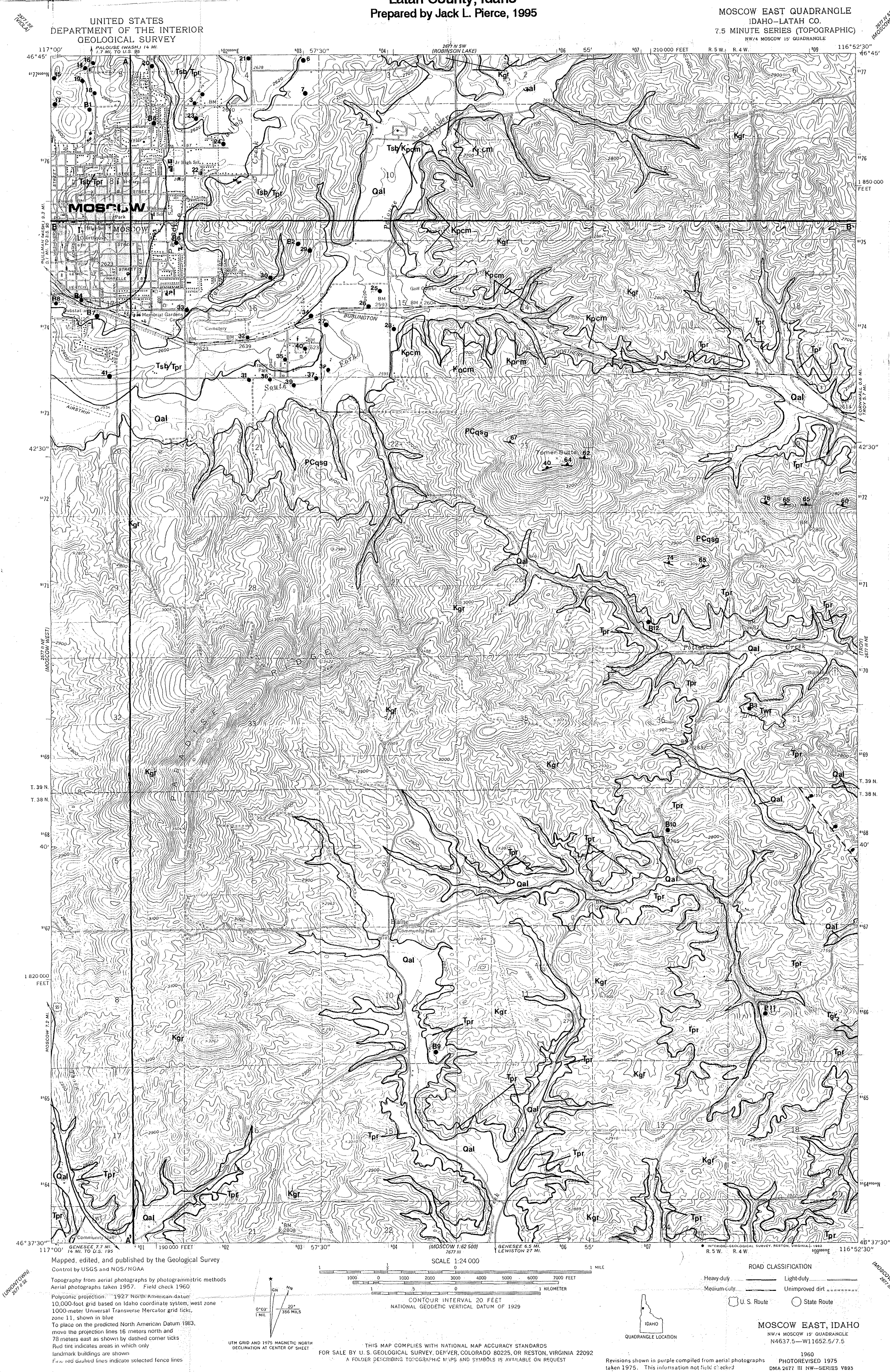
PLATE 1

INTERPRETIVE GEOLOGIC BASE MAP OF THE MOSCOW EAST QUADRANGLE

Latah County, Idaho

Prepared by Jack L. Pierce, 1995



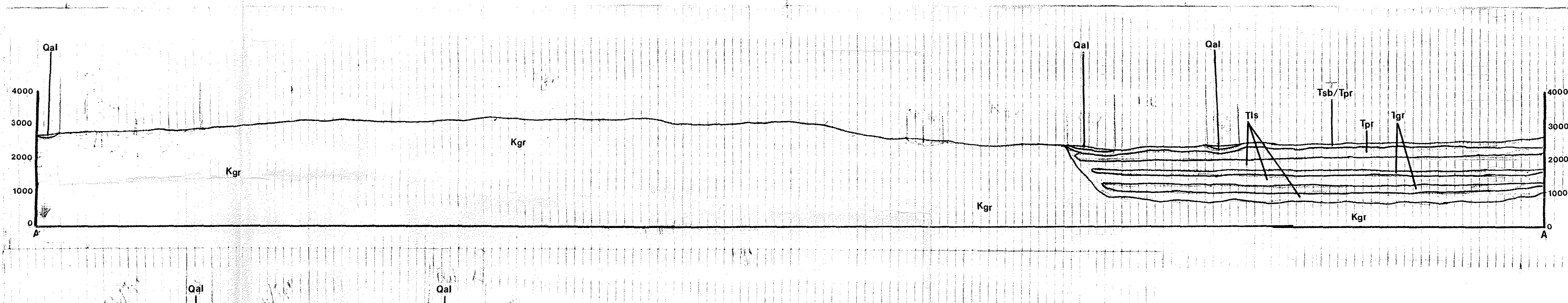
MAP EXPLANATION

Unit	Symbol	Epoch	Period	Era
Aluvium	Qal	Holocene	Quaternary	CENOZOIC
Latah Formation (Sediments of Bovill)	Tsb/Tpr	Miocene	Tertiary	
Saddle Mountains Formation Weissenfels Ridge Member	Twr			
Wanapum Formation Priest Rapids Member	Tpr			
Latah Formation	Tls			
Grande Ronde Formation	Tgr2			
	Kgr		Cretaceous	MESOZOIC
	Kpcm			
	PCqsg			PRECAMBRIAN

LITHOLOGIC DESCRIPTIONS

Symbol	Description
Qal	**ALLUVIUM** - Stream and slope-wash material, commonly composed of reworked loess or mixtures of of loess, basalt and granitoid fragments.
Tsb/Tpr	Yellow, white to gray high alumina clay Quartz sand and silt, feldspar, mica with organic matter common.
Twr	**BASALT** - Medium to coarse-grained, microphenocrysts of plagioclase and olivine in a intergranular matrix with minor glass.
Tpr	**BASALT** - Medium-grained with small phenocrysts of plagioclase and olivine in a matrix of intergranular pyroxene, ilmensite blades and minor devitrified glass.
Tls	**INTERBEDS** - Composed of sand, silt and clay
Tgr2	**BASALT** - Fine-grained to very fine-grained aphyric flows of Grande Ronde chemical type.
Kgr	**GRANITE** - Quartz tonalite, hornblende granodiorite
Kpcm	**MIXED ROCKS** - Intermixed biotite, muscovite gneiss, schist and granitoid rocks.
PCqsg	**QUARTZITE, SCHIST, GNEISS** - 95 to 99 percent recrystallized quartz with interbeded biotite, muscovite, hematite, zircon and apatite.

FAULT, Ball shows upthrown side	_●_●_ _
JOINTS	67 ▲
WELL LOCATIONS	19 ●
BASALT SAMPLES	B6 ●



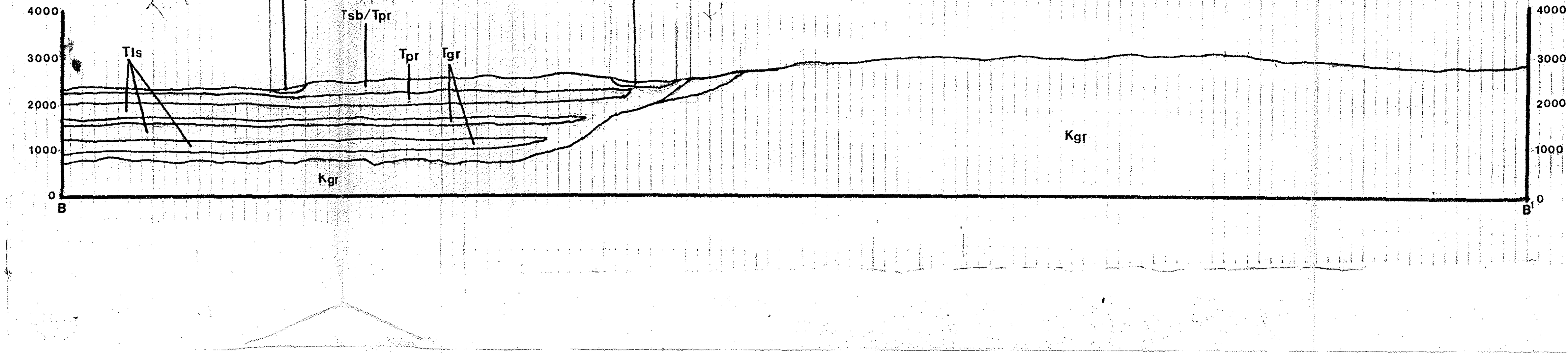


PLATE 2

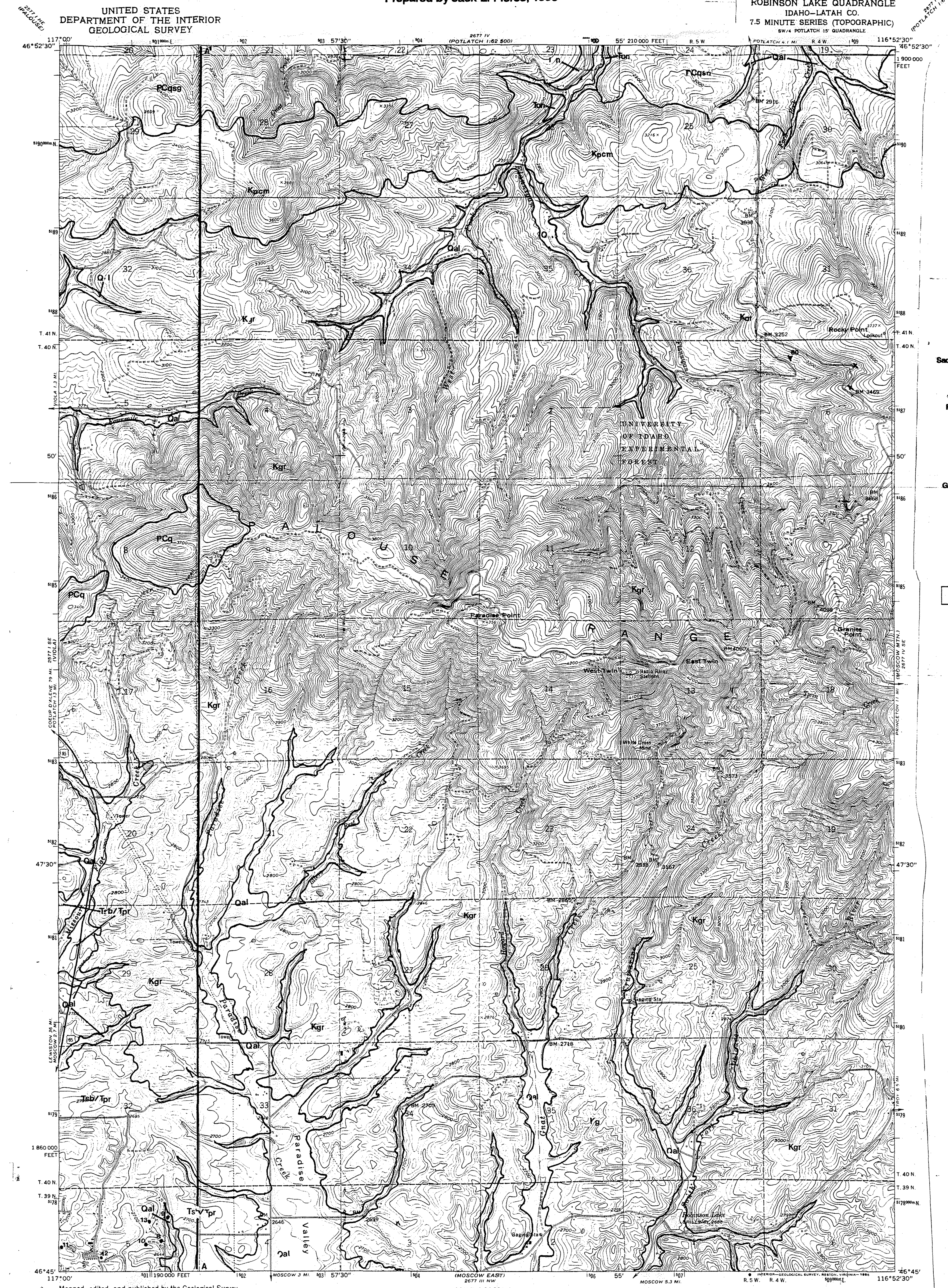
INTERPRETIVE GEOLOGIC BASE MAP OF THE ROBINSON LAKE QUADRANGLE

Latah County, Idaho

Prepared by Jack L. Pierce, 1995

UNITED STATES
DEPARTMENT OF THE INTERIOR
GEOLOGICAL SURVEY

ROBINSON LAKE QUADRANGLE
IDAHO–LATAH CO.
7.5 MINUTE SERIES (TOPOGRAPHIC)
SW/4 POTLATCH 15' QUADRANGLE



Mapped, edited, and published by the Geological Survey

Control by USGS and NOS/NOAA

Topography from aerial photographs by photogrammetric methods
Aerial photographs taken 1957. Field check 1960

Polyconic projection. 1927 North American datum
10,000-foot grid based on Idaho coordinate system, west zone
1000-meter Universal Transverse Mercator grid ticks,
zone 11, shown in blue
To place on the predicted North American Datum 1983
move the projection lines 15 meters north and
78 meters east as shown by dashed corner ticks

Dashed land lines indicate approximate locations
Fine red dashed lines indicate selected fence

There may be private inholdings within the boundaries of
the National or State reservations shown on this map

UTM GRID AND 1984 MAGNETIC NORTH DECLINATION AT CENTER OF SHEET

SCALE 1:24 000

CONTOUR INTERVAL 20 FEET
NATIONAL GEODETIC VERTICAL DATUM OF 1929

THIS MAP COMPLIES WITH NATIONAL MAP ACCURACY STANDARDS
FOR SALE BY U. S. GEOLOGICAL SURVEY, DENVER, COLORADO 80225, OR RESTON, VIRGINIA 22092
A FOLDER DESCRIBING TOPOGRAPHIC MAPS AND SYMBOLS IS AVAILABLE ON REQUEST

QUADRANGLE LOCATION

Revisions shown in purple and woodland compiled from
aerial photographs taken 1982 and other sources
Partial field check by U.S. Forest Service. Map edited 1984

ROAD CLASSIFICATION
Heavy-duty .... Light-duty ....
Unimproved dirt ....
U. S. Route

ROBINSON LAKE, IDAHO
SW/4 POTLATCH 15' QUADRANGLE
N4645—W11652.5/7.5

1960
PHOTOREVISED 1984
DMA 2677 IV SW—SERIES V893

MAP EXPLANATION

Unit	Epoch	Period	Era
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Wanapum Formation Priest Rapids Member Tpr	Miocene	Tertiary	CENOZOIC
Latah Formation Tls	Miocene	Tertiary	CENOZOIC
Grande Ronde Formation Tgr2	Miocene	Tertiary	CENOZOIC
Kgr		Cretaceous	MESOZOIC
Kpcm		Cretaceous	MESOZOIC
PCg PCqsg			PRECAMBRIAN

LITHOLOGIC DESCRIPTIONS

Unit	Description
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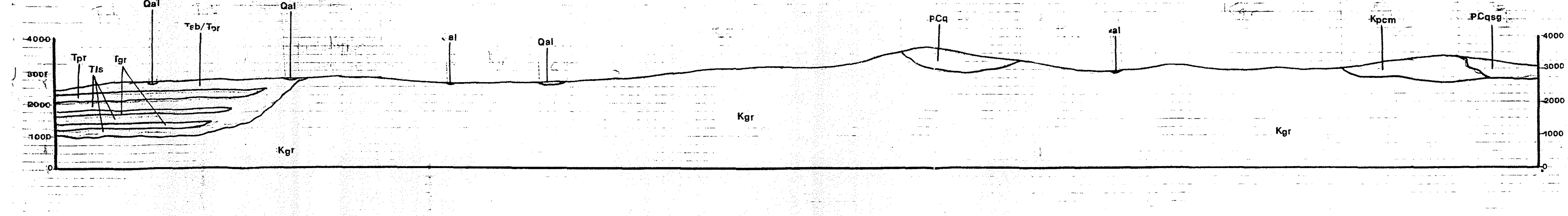
Ton	BASALT - Consist of large phenocrysts of plagioclase in a dense groundmass.
Tpr	BASALT - Medium-grained with small phenocrysts of plagioclase and olivine in a matrix of intergranular pyroxene, ilmensite blades and minor devitrified glass.
Tls	INTERBEDS - Composed of sand, silt and clay
Tgr2	BASALT - Fine-grained to very fine-grained aphyric flows of Grande Ronde chemical type.
Kgr	GRANITE - Quartz tonalite, hornblende granodiorite
Kpcm	MIXED ROCKS - Intermixed biotite, muscovite gneiss, schist and granitoid rocks.
PCq	QUARTZITE
PCqsg	QUARTZITE, SCHIST, GNEISS - 95 to 99 percent recrystallized quartz with interbeded biotite, muscovite, hematite, zircon and apatite.

JOINTS	▲ 5
WELL LOCATIONS	● 19



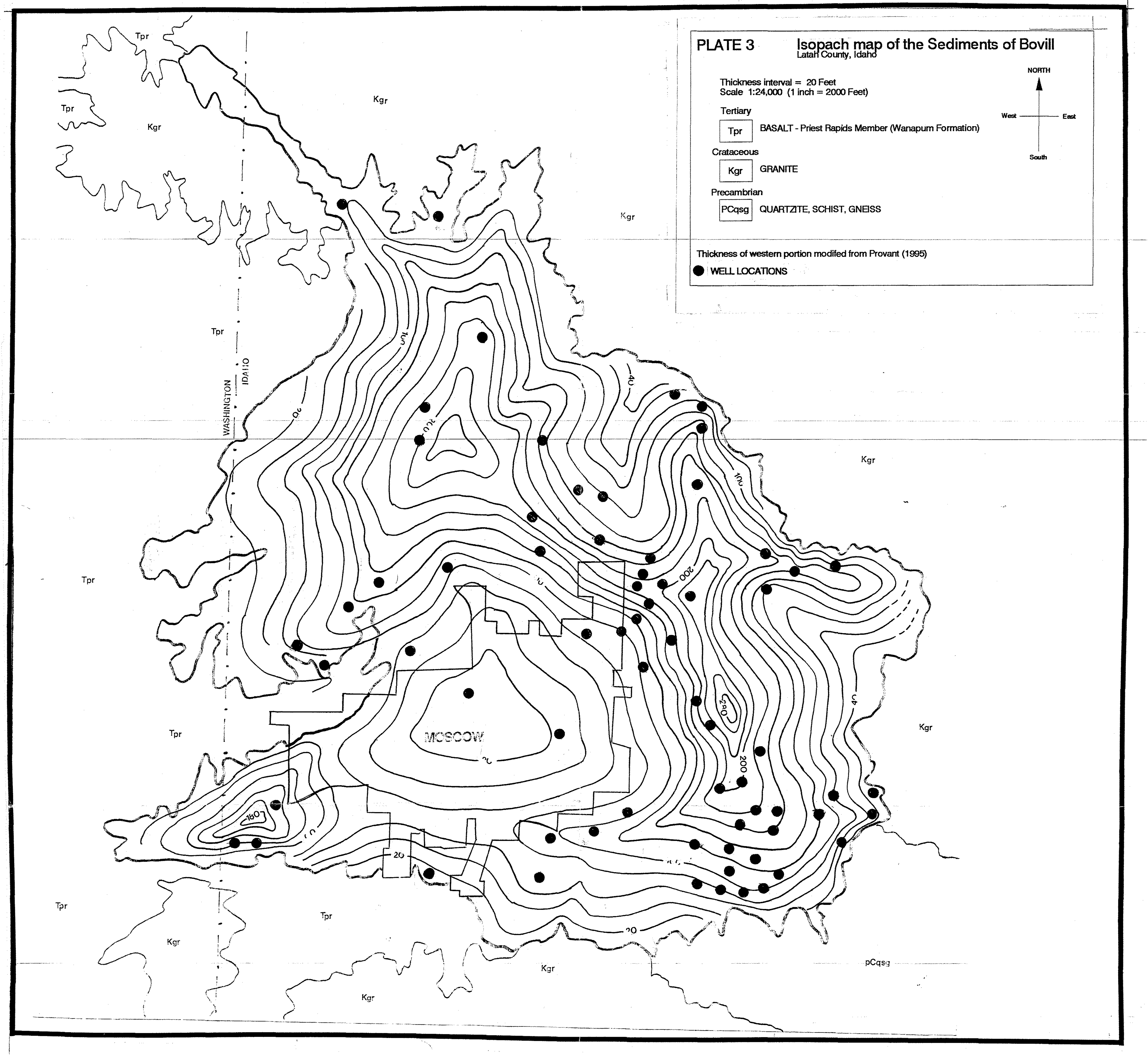


PLATE 3 Isopach map of the Sediments of Bovill

Latah County, Idaho

Thickness interval = 20 Feet
Scale 1:24,000 (1 inch = 2000 Feet)

Tertiary

Tpr	BASALT - Priest Rapids Member (Wanapum Formation)

Crataceous

Kgr	GRANITE

Precambrian

PCqsg	QUARTZITE, SCHIST, GNEISS

Thickness of western portion modifed from Provant (1995)

● WELL LOCATIONS

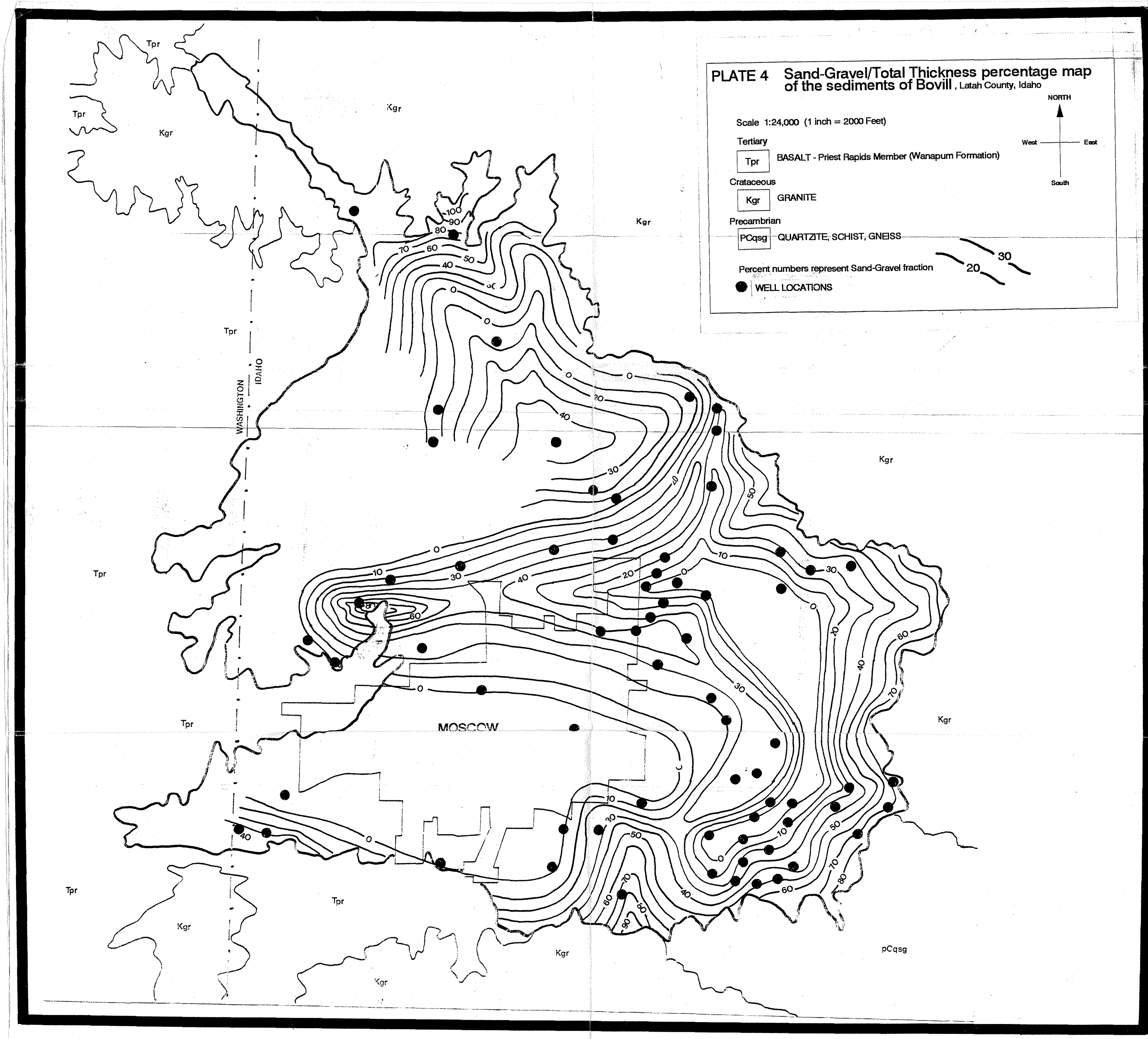


PLATE 4 Sand-Gravel/Total Thickness percentage map of the sediments of Bovill, Latah County, Idaho