GEOLOGIC REPORT ON MOSCOW MONITORING WELLS

John Bush, December, 2006

INTRODUCTION

Four monitoring wells were established on the north edge of University of Idaho land in Moscow, Idaho during the summer of 2006. The wells are on the south side of a gravel and dirt county road. Three of the four wells are located (Figure 1) in the northwestern corner of ¼ SE., ¼ SE., Sec. 1, R. 6 W., T. 39 N. The fourth well is located approximately 1800 feet east of the three wells in Sec. 6, R. 5 W., T. 39 N. The approximate elevations of the wells are 2600 feet for the three wells and 2620 feet for the other well. The Palouse Basin Aquifer Committee (PBAC) will be establishing accurate GPS locations and elevations. The wells have been numbered 1-4 from shallowest (72 ft, MMW No. 1) to deepest (735 ft, MMW No. 4). This report focuses on wells 1 and 4.

Moscow is located along the eastern margin of the Columbia Plateau and is underlain by Miocene sediment and basalt of the Columbia River Basalt Group (CRBG) exceeding 1600 feet in total thickness. The area is surrounded on the north, east, and south by pre-Miocene igneous and metamorphic rocks that rise in elevation and make a C-shaped geologic basin open to the west were the CRBG units extend into Whitman County of Washington. Basalt flows are interlayered with sediment units that in general thicken to the east and northeast. Overall, sediment sequences makeup 60-70% of the total GRBG in the Moscow area.

Four Miocene basalt flows and four sediment sequences were encountered during drilling. Samples were analyzed using a binocular scope and lithology logs were completed for the shallowest and deepest wells (Tables 1 and 2). Major and trace element chemistry for each basalt unit was determined from rotary chips (Tables 3 and 4). Chemistry and sequence position was used to correlate the basalt flows to local wells and regional stratigraphic units (Figure 2). The sediments were drilled primarily by mud-rotary and accurate sampling was difficult for some intervals. Figure 3 illustrates the approximate position of installed screens relative to stratigraphic unit for the four wells.

A north to northeast trending cross-section using Well No. 4 as the focal point was constructed from the data obtained (Plate One). Regional correlations into the state of Washington were determined from the chemistry data and these correlations are discussed in the text.

The chemical analyses were done by the GeoAnalytical Laboratory at Washington State University.

BASALT UNITS

Basalt flows encountered are from three different formations of the Miocene Columbia River Basalt Group. From oldest to youngest these are the Grande Ronde, Wanapum and Saddle Mountains formations. The discussion of the units encountered is from the oldest to the youngest. The deepest Grande Ronde Basalt (720-735 ft) was analyzed twice for chemistry. It is interpreted to belong to the Wapshilla Ridge flows of the Winter Water Member, R2 magnetostratigraphic unit. These flows according to Reidel and others (1989), are high silica flows characterized by low MgO (3.00 to 4.00 wt%) and high to very high TiO_2 exceeding 2.6 wt%. In Pullman, seven miles to the west, the Grande Ronde has been divided from base upward into the R1, N1, R2, and N2 sequences (Bush and Garwood, 2003). Comparisons to existing chemistry show that basalt with similar high silica and TiO_2 occurs in at least four wells. The depths of these samples are as follows: WSU No. 7 (540 ft), WSU No. 6 (525 ft), Pullman No. 5 (428 ft), and Pullman No. 7 (425 ft). These correlations are useful for understanding the geohydrology of the Moscow-Pullman basin, but must be considered tentative until additional data is available.

The only sequence chemistry data available from a deep well in Moscow comes from information presented by Brown (1976). That data was collected using outdated XRF machines by today's standards. However, he reports analyses from the 625- to 725-foot interval in University Well No. 3 that is useful. That chemistry is similar to characteristics of the R2 unit. Other data presented by Brown (1976) suggests that the top of the R2 occurs between 532 and 585 feet in the DOE test well located approximately 2 miles west of the Idaho-Washington boundary.

The uppermost Grande Ronde was encountered between 499 and 585 feet (top at approximately 2100 ft) in MMW No 4. A review of characteristics of upper Grande Ronde flows by Reidel and others (2004) indicates that the basalt belongs to the Sentinel Bluffs Member of the N2 magnetostratigraphic unit, which consists of several flows at the top of the Grande Ronde (Reidel and others, 1989). The chemistry from this flow was also compared to existing Moscow-Pullman data. These comparisons indicate that this flow in MMW No. 4 correlates to the basalt of Stember Creek (Figure 4) described by Reidel (2005). A flow with very similar chemistry occurs at the top of the Grande Ronde in the Palouse city well at an elevation of approximately 2100 ft.

Comparisons to the DOE test well and wells in the City of Pullman indicate that at least three to four flows younger than the uppermost Grande Ronde in MMW No. 4 makeup the top of the Grande Ronde at those localities. These correlations show that the top of the N2 thins rapidly and becomes overlain by thick sediments of the Latah Formation near the state line. This change causes the top of the Grande Ronde surface to drop from approximately 2400 feet in the DOE test well in Washington to approximately 2100 feet in MMW No. 4 over a distance of less than 3 miles (Figure 5). Although the chemistry was much less precise than used for this report, Brown came to the same conclusion over 30 years ago (Brown, 1976).

One basalt flow of the Wanapum Formation was encountered from 49 to 276 feet in MMW No. 4. Three samples were analyzed and the basalt has a Lolo chemical type and belongs to the Priest Rapids Member. Outcrops of this member occur throughout the Palouse Basin and has been encountered in hundreds of wells. It is relatively consistent across the Moscow area before it thins out near to the edge of the pre-Miocene rocks that define the northern, eastern and southern boundary. Towards the west the basalt thins to less than 100 feet in thickness over Pullman, but thickens again west of the city. Outcrops and well data show that, in places, the basalt consists of two flow units with a vesicular zone or thin interbed separating the upper and lower portions. Hopper and Webster (1982) report that the Wanapum in Pullman locally consists of the Rosalia chemical type, which also belongs to the Priest Rapids Member.

A portion of a Saddle Mountains flow was encountered in MMW No. 1. The basalt in that well is only 10 feet thick and is highly iron stained and weathered. The surface casing was loosely packed with crushed basalt and the drill sample was contaminated. Therefore, the chemical analysis was not reported. The results however, contained enough features to determine that it to belong to the Weissenfels Ridge Member-Lewiston Orchards flow. This basalt has been noted in only a few localities within the Moscow area, but it has been mapped approximately 2000 feet north of the well (Hooper and Webster, 1982; Bush and Provant, 1998a). The Lewiston Orchards flow is interlayered with the uppermost Latah sediments (sediments of Bovill). The flow does not have extensive lateral continuity and it is concluded that it comes from a local vent.

SEDIMENT UNITS

Four units of sediments totaling a stratigraphic composite thickness of 414 feet were encountered during the drilling and construction of the monitoring wells. Collectively they belong to the Latah Formation and comprise over 50% of the entire sequence encountered. Westward away from the eastern edge of the Columbia Plateau these units thin, are in places not mapable at 1:24,000, and are often considered to be part of the basalt units. However, two specific names have been applied to part of this sequence in the Moscow area.

The term "sediments of Bovill" has been applied to the uppermost Miocene sediments which overlie the Priest Rapids Member (Bush and Provant, 1998). These sediments range up to 250 ft in thickness, and in general thin from east to west (Pierce, 1998). In MMW No. 1 these sediments exceed 72 feet.

Sediments that separate the base of the Wanapum and the uppermost Grande Ronde Basalt are referred to as the Vantage Member (Bush and Provant, 1998). In MMW No. 4 this unit is 225 feet thick. The term comes from outcrops near Vantage, Washington, and was utilized in regional correlations into the Pullman area (Siems and others, 1974).

The sediments in the Moscow area were deposited primarily in response to the emplacement of basalt flows advancing from the west. The sediments consist of alternating upward fining sequences of gravel, sand, silt, and clay. The uppermost sediments also contain laterally extensive beds of peat in the southeastern portion of the basin (Fairley and others, 2006). Towards the edges of the pre-Miocene rocks the sediments grade into weathered slightly transported and non-transported weathered granitic regolith.

Estimates of sand, silt, and clay percentages were difficult to determine for the monitoring wells because of drilling methods. The sediments of Bovill consisted of approximately 20% gravel and sand. The Vantage contained approximately 25% sand and gravel. The lowermost interbed between the Grande Ronde flows contained approximately 33% sand. The larger grains of the sand and gravel intervals are well sorted in terms of size, but the sediments contain abundant clay and silt matrix. In addition, the grains are generally not well rounded.

Hosterman and others (1960), Calvin (1964), Lin (1967), Pierce (1998), and Fairley and others (2006) provide details on much of the sediment sequence in the Moscow area.

GEOLOGIC CROSS SECTION

A geologic cross-section ABC (Plate One) was constructed in two directions from MMW No. 4 (Figure 1). Data from the Naylor farm to the northeast and outcrops to the southwest of the monitoring wells provides some base control. The AB part of the section has excellent control from city and University deep wells. However, there are no deep wells between MMW No. 4 and Naylor farm. Moscow Well No. 6, located east of the monitoring wells, indicates that there is an eastward increase in sediment content, which is consistent with previous cross-sections drawn E-W through Moscow. The increase in sediment shown on the cross-section towards the northeast is probably correct. However, the depth to pre-Miocene rocks should be considered open to interpretation.

Overall the sediment-basalt relations illustrated on Plate One are consistent with stratigraphic and geologic cross-sections in Lin (1967), Crosby and Calvin (1960), Calvin (1964), Brown (1976), Bush and Provant (1998a and b), Bush and others (1998), and Bush and others (2000). However, there are two differences that should be noted. First, the earlier geologic cross-sections show Pleistocene loess in contact with the basalt. Review of over 100 shallow test holes for construction during the past 15 years in the Moscow area show that the loess is generally thin and Miocene sediments overlie the basalt flows at all localities except along the edges of flood plains in the western part of the basin. Surficial maps of the Moscow area illustrate and discuss the relations of the unconsolidated materials (Othberg and Breckenridge, 2001a and b).

The second difference between earlier and recent cross-sections is the method of illustrating contact relations with pre-Miocene rocks. Geologic mapping of this contact throughout northern Idaho and eastern Washington has shown that basalt resting directly on pre-Miocene rocks is very rare. Therefore, the basalt flows on Plate One are shown to be separated from the pre-Miocene rocks by associated sediments.

SUMMARY

The major geologic findings from the Moscow Monitoring wells are as follows:

1) Four basalt flows belonging to three different formations of the Columbia River Basalt Group were encountered in the wells.

2) Latah Formations sediments make up over 50% of the sequence.

3) Sand and gravel make up between 20-33% of the sediment layers.

4) The entire sequence is consistent with eastward and northeastward decrease in basalt as the

sediment intervals thicken.

5) The units encountered are consistent with those described and illustrated on published geologic maps and reports.

6) Chemistry data show that the uppermost Grande Ronde flow is the basalt of Stember Creek, which is similar to the upper Grande Ronde flow in Palouse, Washington. The same data when compared to data from Washington wells show a rapid eastward thinning of 400 to 500 feet of Grande Ronde just west of the Washington-Idaho boundary.

7) The lower Grande Ronde basalt encountered in MMW No. 4 is correlated to the Wapshilla Ridge flows of the R2 magnetostratigraphic unit. Similiar flows of the R2 can be tentatively located in wells located in Pullman.

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Table 1. Lithologic Log for Moscow Monitoring Well No. 1 (Bush, 26 June 2006).

Unit	Depth (feet)	Description
Top soil	0–8	Top soil, dark dusky brown (5 yr 2/2).
Latah Formation (Sediments of Bovill Member)	8–19	Clay, dark yellowish orange (10 yr 6/6), slightly silty.
	19–25	Granule gravel, 2mm to 6mm, average 4mm, occasional pebble 10-20mm, very angular to subangular, 99% quartz, minor muscovite and feldspar, most grains transparent, very light gray (N8) to yellowish gray (5 yr 8/1), water bearing. Samples are stained and contain yellow clay. Percent clay undetermined, but believed to be relatively high.
Saddle Mountains Basalt (Weissenfels Ridge Member, Lewiston Orchards Flow)	25–35	Basalt, fine-grained, occasional plagioclase phenocryst 3-4mm, medium dark gray (N4), Fe and Mn stains on uppermost and lowermost chips.
Latah Formation (Sediments of Bovill Member)	35–40	Clay, pale blue (5B 6/2) with white (N9) centers, when wet color changes to blue and generally recorded as blue clay by most drillers, very slick.
	40–47	Clay, varied colored, yellowish gray (5 yr 7/2) to pale yellowish orange (10 yr 8/6), minor black streaks (N1), approximately 10% silt and very fine sand.
	47–58	Clay, pale yellowish orange (10 yr 7/2), very slick.
	58–70	Granule gravel, 3-5mm, coarser in places 6-7mm, occasional 10-15mm pebble, 99% quartz, minor muscovite and feldspar, subangular to subrounded. Samples stained yellow and contained yellow clay. Not possible to estimate percent of clay.
	70–72	Clay, pale yellowish orange (10 yr 7/2).

Table 2. Lithologic Log for Moscow Monitoring Well No. 4 (Bush, 26 June 2006).

Unit	Depth (feet)	Description
Top soil	0–2	Top soil, dark dusky brown (5 yr 2/2).
Latah Formation (Sediments of Bovill Member)	2–30	Clay, dark yellowish brown (10 yr 4/2), slightly silty.
	30–50	Clay, white (N9) to yellowish gray (5 yr 7/2).
Wanapum Basalt Priest Rapids Member (Lolo chemical type)	50–60	Basalt, vesicular, fine-grained, medium-gray (N5), iridescent coatings common.
	60–70	Basalt, vesicular.
	70–110	Basalt, dense, fine to medium-grained, occasional plagioclase phenocryst, medium-gray (N5), fractured at 110 ft.
	110–245	Basalt, dense, same as above.
	245–247	Basalt gravels, 2-3cm, angular to sub-rounded, same as host rock, interpreted as non-depositional.
	247–276	Basalt, dense, fine to medium-grained, occasional plagioclase phenocrysts.
Latah Formation (Vantage Member)	276–278	Sand, coarse to very coarse (1/2mm to 2mm), 90% quartz, 10% basalt?, minor muscovite and feldspar?, subangular to subrounded, sample mixed with chips from above.
	278–285	Clay, white (N9) to very light gray (N8).
	285–290	Sand, very coarse (1.5-2mm), 90% quartz, 10% basalt?, minor muscovite, subrounded, fairly well sorted, rare wood fragments.
	290–335	Sand, silt and clay, occasional granule of quartz and some subrounded basalt (3-5%). Abundant wood fragments and sample sticky 299-305 feet.
	335–360	Sand, silt, and clay, greenish gray clay in overflow ditch, but not in samples. Sand is coarse to very coarse-grained.
	360–370	Clay, brownish gray (5 yr 4/1), sandy?, abundant wood fragments.
	370–410	Sand, coarse .5 to 1mm to very coarse (1.5mm), subangular to subrounded, fairly well sorted with silt and clay, minor wood fragments with some abundant intervals, color of mud is greenish gray, abundant silt in overflow ditch after drilling, occasional very fine-grained well rounded siltite granule.
	410–423	Sand, slightly coarser than above.
	423–485	Clay and silt, mud a moderate brown (5YR 4/4) in color.
	485–499	Clay and silt, mud a grayish yellow green (5GY 7/2) in color.
Grande Ronde Basalt (N2 Member)	499–510	Basalt, vesicular with small openings, iridescent coatings.
	510–580	Basalt, dark gray (N3), very fine-grained, dense.
	580–585	Basalt, dark gray (N3), vesicular and iron stained, minor vesicle fillings.
Latah Formation	585–620	Clay, grayish green (10GY 5/2), silty in places.
	620–665	Sand, coarse to very coarse (1/2mm to 2mm), subangular, 95% quartz with siltite, basalt?, and minor muscovite fragments.
	665–720	Clay, brownish gray (5YR 4/1), silty in places.
Grande Ronde Basalt (R2 Member)	720–735	Basalt, dark gray (N3), very fine-grained.

Table 3. Major Oxide Chemistry for Moscow Monitoring Well No. 4 (2006).

Sample Depth (ft)	SiO_2	TiO_2	Al_2O_3	FeO	MnO	MgO	CaO	Na_2O	K_2O	P_2O_5
75	50.55	3.33	13.99	13.11	0.23	4.64	9.52	2.70	1.14	0.78
245	49.61	3.37	14.24	12.99	0.23	5.40	9.57	2.70	1.08	0.81
270	50.23	3.16	13.70	13.66	0.23	5.23	9.20	2.72	1.13	0.74
510	55.30	1.77	14.77	9.91	0.21	4.40	9.13	2.82	1.39	0.29
545	54.26	1.72	14.52	10.95	0.20	4.87	8.97	2.83	1.38	0.30
730	55.59	2.78	14.84	10.12	0.19	3.16	7.74	3.14	1.68	0.77
735	55.94	2.71	14.57	10.59	0.19	2.98	7.47	3.17	1.89	0.50

Normalized Major Elements (Weight %)

Table 4. Trace Element Chemistry for Moscow Monitoring Well No. 4 (2006).

Sample Depth (ft)	Ni	Cr	Sc	V	Ba	Rb	Sr	Zr	Y	Nb	Ga	Cu	Zn	Pb	La	Ce	Th	Nd
75	45	101	39	376	620	28	290	190	43	14.4	23	42	146	7	29	63	4	36
245	49	102	40	379	677	24	295	180	45	15.8	23	43	150	7	30	65	4	42
270	49	97	38	366	531	28	281	182	42	14.7	21	42	141	9	30	55	4	33
510	34	107	37	330	641	35	305	147	30	10.1	21	58	110	7	19	41	4	25
545	38	109	36	318	512	34	292	145	30	10.0	20	65	121	37	17	38	3	22
730	22	17	35	420	1087	45	362	206	43	13.1	24	31	130	11	28	66	5	37
735	14	13	34	425	971	49	349	202	41	13.3	22	29	141	10	27	54	5	33

Unnormalized Trace Elements (ppm)

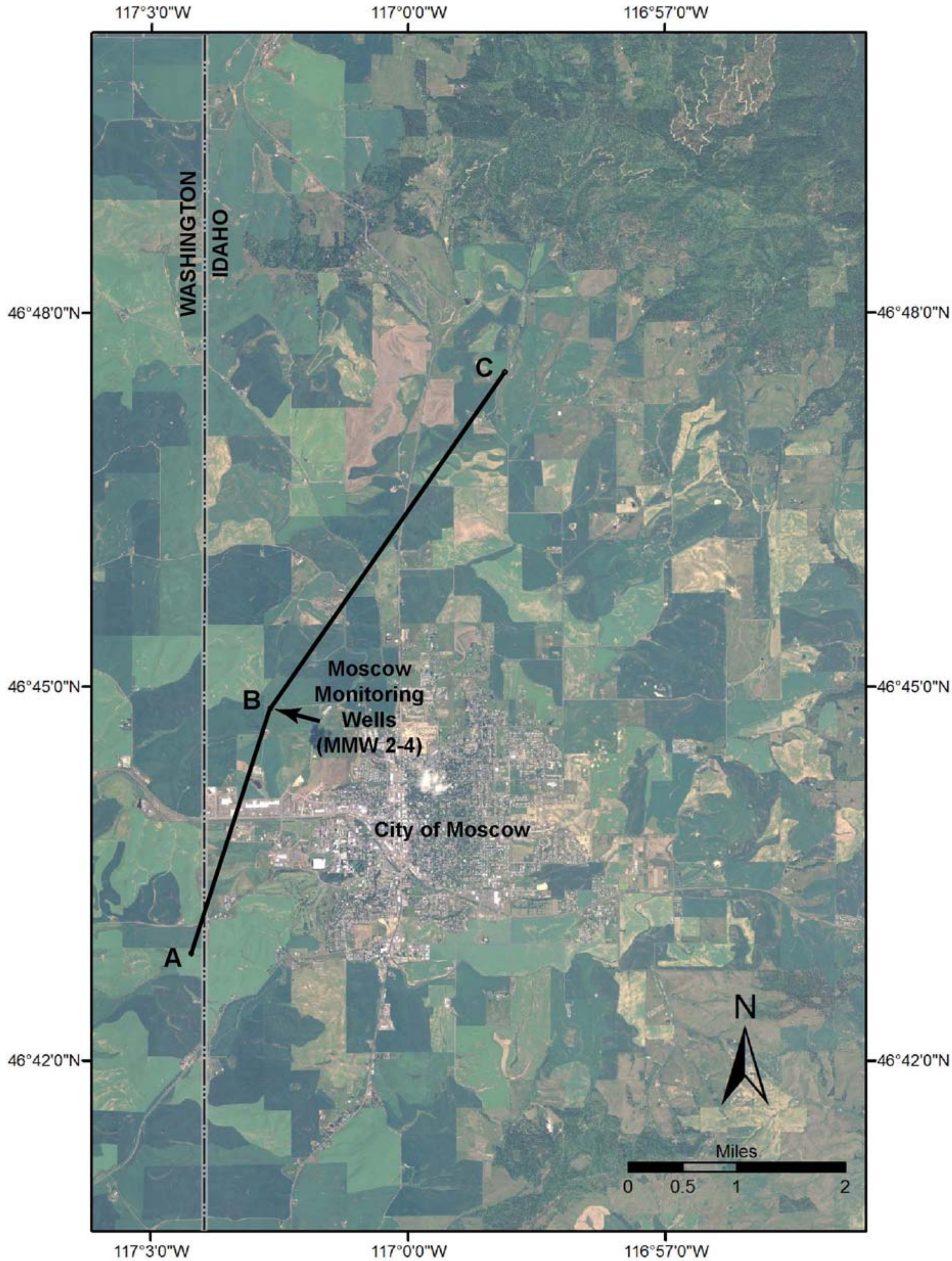

Figure 1. Location of MMW 2-4, and Geologic Cross-Section ABC.

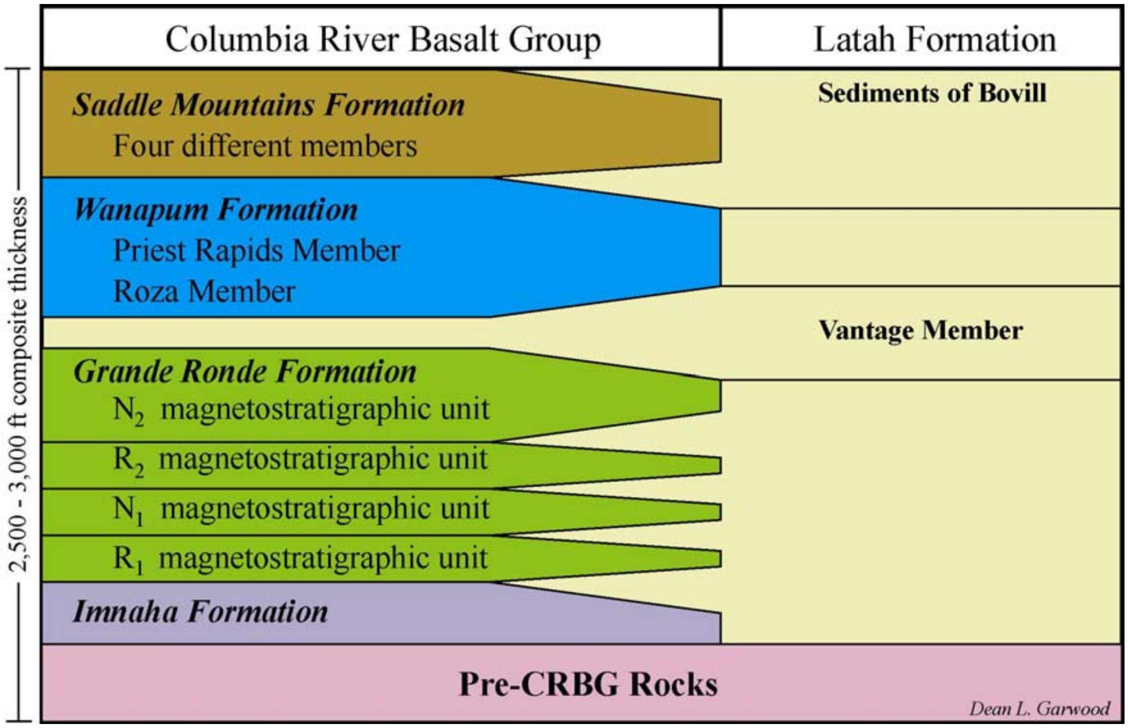

Figure 2. Stratigraphic units of the Columbia River Basalt Group, Palouse Basin, Idaho-Washington.

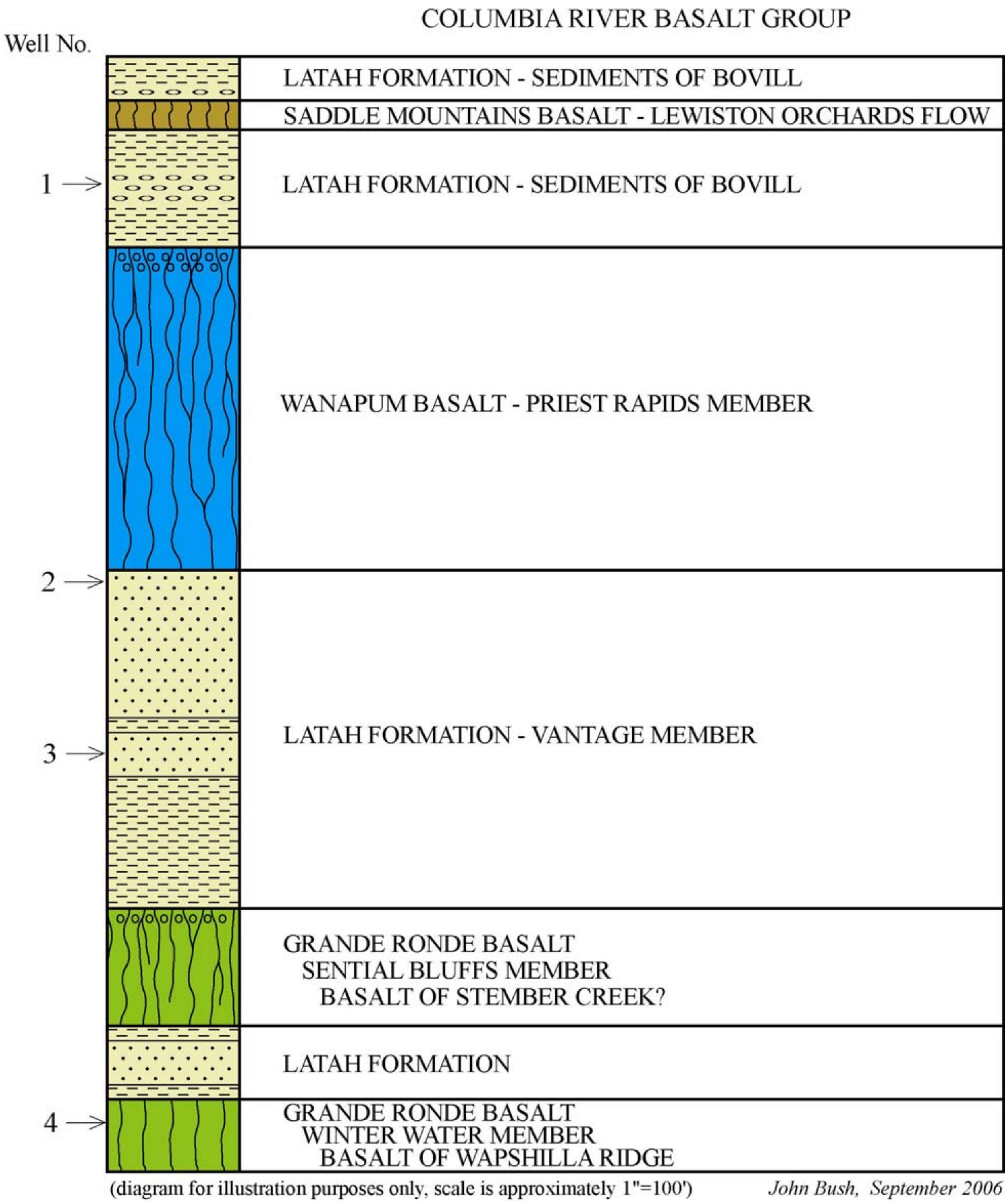

Figure 3. Composite Stratigraphic Column for Moscow Monitoring Wells (2006).

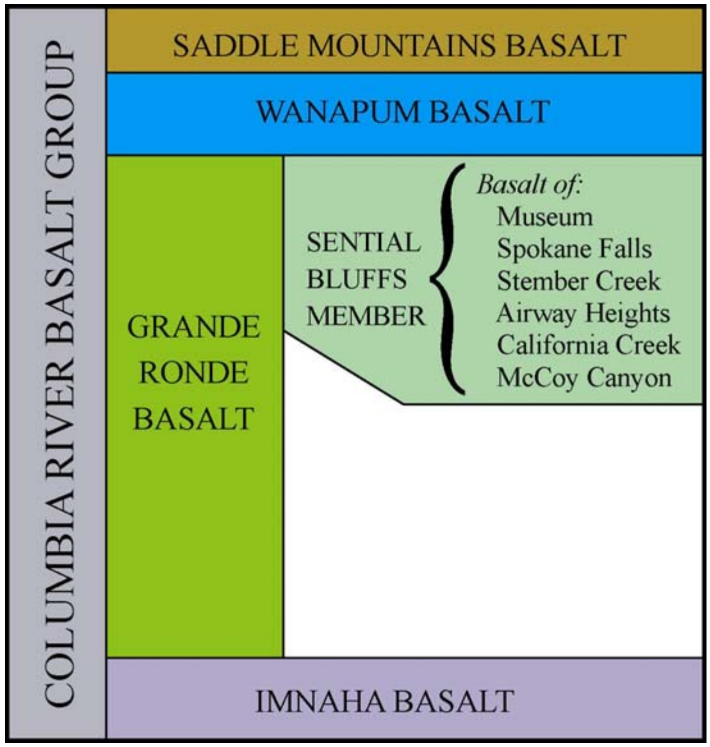

Figure 4. Subdivision of the Upper Grande Ronde Basalt by Riedel (2005).

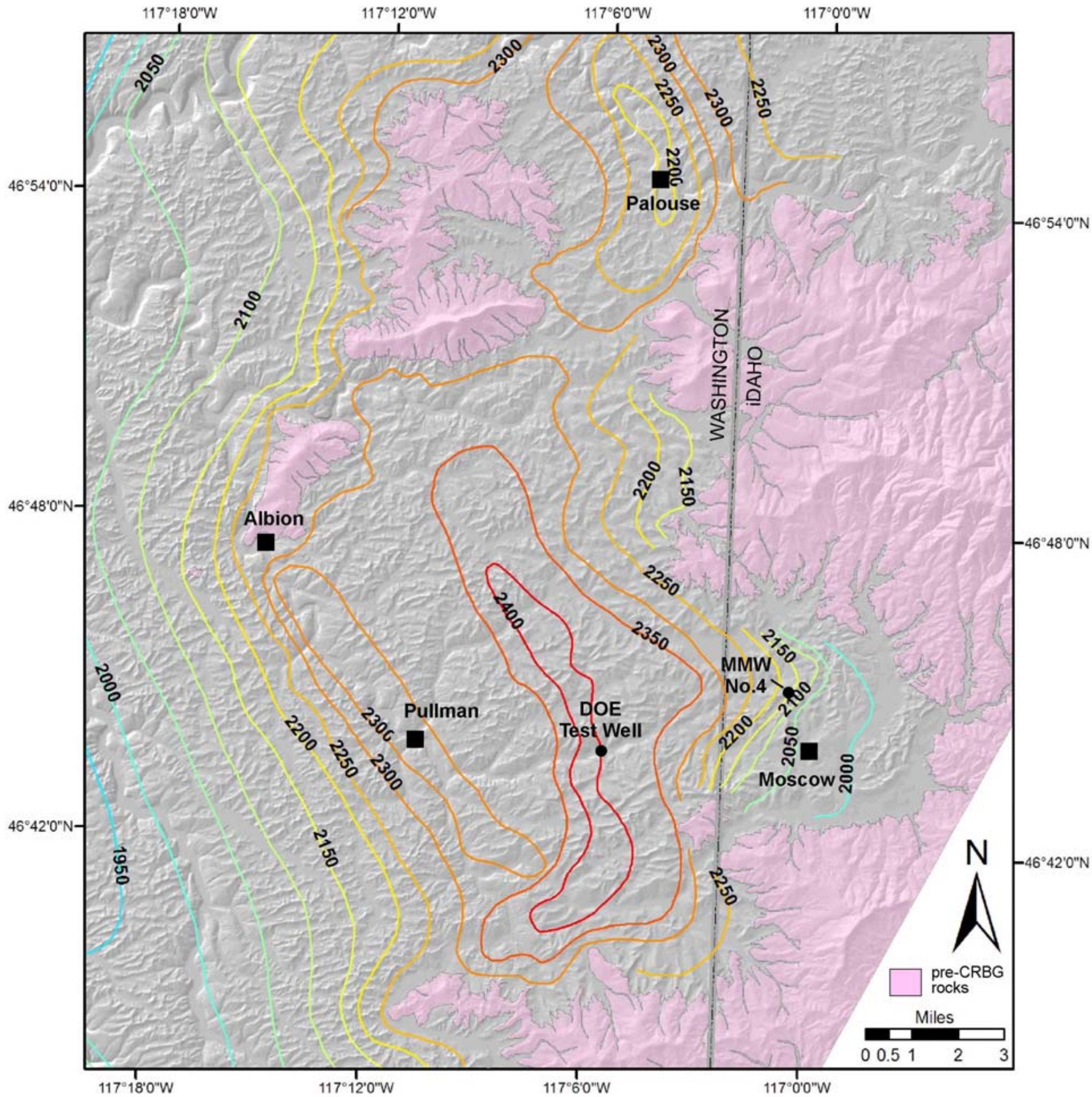

Figure 5. Structural Contour Map of the Top of the Grande Ronde Basalt Superimposed on a Physiographic Map of the Palouse Basin (contour interval=50').

PLATE ONE - Geologic Cross-Section ABC Showing Correlations to Surrounding Wells.