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A Preliminary Investigation of the Magnetostratigraphy of the Ringold Formation

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Woodward-Clyde Consultants

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A PRELIMINARY INVESTIGATION
OF THE MAGNETOSTRATIGRAPHY
OF THE RINGOLD FORMATION

by

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May 1979

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A PRELIMINARY INVESTIGATION OF THE MAGNETOSTRATIGRAPHY
OF THE RINGOLD FORMATION

INTRODUCTION

The Ringold Formation consists of lacustrine and fluvial deposits overlying the Columbia River Basalt. Newcomb (1958) described the conglomerate and overlying finer grained sediments of the Ringold Formation at the type locality in the White Bluffs and extended the Ringold Formation to include the subsurface "blue clays" beneath the conglomerate unit. For this study, the three facies of the Ringold Formation are referred to as the upper, middle, and lower Ringold units. These units are based on the occurrence of the clay, silt, sand, and ash in the upper unit, sandy conglomerate in the middle unit, and the "blue clay," consisting of clay, sand, and silt, in the lower unit. In the central portion of the Pasco Basin, the Columbia River has eroded the upper Ringold and some portions of the middle Ringold unit. Elsewhere, the caliche cap on the upper Ringold unit and the low rainfall have prevented much dissection of the Ringold Formation. The White Bluffs along the Columbia River are the best and most complete exposure of the upper Ringold unit and the upper portion of the middle Ringold unit. Outcrops of these units are sparse north of the Pasco Basin. The lower portion of the middle Ringold unit and the lower Ringold unit are not exposed at the surface and are available only as core.

The Ringold Formation, because of its thickness, extent, and age, is an excellent unit in which to detect and possibly date the deformation that has occurred since deposition of the basalt. However, the fluvial and lacustrine nature of the Ringold Formation makes lithologic correlation of units over as few as several kilometers difficult, particularly in drill

holes. The age of the Ringold Formation is not well known, although several authors have discussed the age of the upper Ringold Formation on the basis of sparse fossil evidence. Gustafson (1978) has authored the most comprehensive paleontological report on the Ringold Formation.

A preliminary investigation of the magnetostratigraphy of the upper Ringold unit exposed at White Bluffs was conducted by Woodward-Clyde Consultants (1979) for United Engineers and Constructors. This work supported earthquake studies that were performed for Washington Public Power Supply System, Inc. (WPPSS). The study demonstrated, with samples collected at the White Bluffs and from loess deposits near the cities of Ellensburg and Yakima, that both normal and reversed magnetic polarities were present and that paleomagnetism could be useful in the dating and correlation of these units. Another paleomagnetic study, in progress, is being conducted in the Ringold Formation by G. Kukla and C. Neville of the Lamont-Doherty Geologic Observatory at Columbia University. Their work supports part of a larger study concerned with a detailed world-wide chronology of Pliocene-Pleistocene-age rocks. Work presented in this report was conducted by Woodward-Clyde Consultants under contract to Rockwell Hanford Operations (Rockwell) to further evaluate the magnetostratigraphy of the Ringold Formation.

OBJECTIVES AND SCOPE

One objective of this study was to investigate the paleomagnetism of the upper Ringold unit exposed at one location in the White Bluffs in enough detail to resolve, with reasonable confidence, the magnetostratigraphy of the rock units sampled. The other objective was to evaluate, in a preliminary manner, the paleomagnetic favorability and

magnetostratigraphy of the subsurface Ringold Formation in the Pasco Basin and at selected exposures outside the Pasco Basin.

The scope of this study was the collection of 300 paleomagnetic samples, their measurement, and analysis. During this study, samples were collected from the White Bluffs, from core recovered from six drill holes on the Hanford Site, and from two surface exposures outside the Pasco Basin. As listed in Table 1, a total of 294 samples was collected during three field visits between November 17, 1978 and March 16, 1979. Of these 294 samples, 146 are from outcrops in the Pasco Basin, 54 from outcrops outside the Pasco Basin, and 94 from subsurface sections. A total of 2928 paleomagnetic measurements, averaging ten measurements per sample, were performed on these samples.

METHOD OF STUDY

The design of the field- and core-sampling programs and locations were selected in conjunction with Rockwell personnel. Field reconnaissance was made to locate the best local exposures for sampling. Exposures were selected on the basis of access, completeness of section, absence of complex landsliding, a minimum of talus cover, and a minimum of weathering. The lithologies of the sections sampled were measured and described. At the beginning of a collection traverse, a sample horizon spacing was chosen and the geologist describing the section numbered and marked the horizons to be sampled with flagging. During this flagging, finer grained sediments were, if locally present, preferentially selected for sampling.

TABLE 1

NUMBER OF SAMPLES, MEASUREMENTS, AND
AVERAGE NUMBER OF MEASUREMENTS PER
SAMPLE, BY SECTION

<u>Section</u>	<u>Number of Samples</u>	<u>Number of Measurements</u>	<u>Average Number of Measurements/Sample</u>
Parsons Canyon	56	572	10.21
Ringold Flat	90	918	10.20
Taunton	24	314	13.08
Moses Lake	18	146	8.11
Northern White Bluffs	12	107	8.92
Total samples from outcrop	200	2057	10.29
<u>Core Holes</u>			
DH-6	22	211	9.56
DH-7	22	211	9.56
DH-9b	8	64	8.00
DH-11	16	134	8.38
DH-13	10	95	9.50
DH-17	16	156	9.75
Total samples from down hole core	<u>94</u>	<u>871</u>	9.27
TOTAL	294	2928	9.96

The units to be examined in the core sections were selected using core logs. Horizons to be sampled were chosen at the core repository by inspection of the cores after removing their foil wrapping. Cores that retained moisture and those containing finer grained sediments were preferentially sampled. Paired samples were collected at all horizons and were carved or cut, generally one above the other, from the central portion of the core in an effort to avoid any mud rind on the core, zones of drilling mud intrusion, or areas where mechanical disturbance could be expected.

In all but a few cases, the collection and preparation of paleomagnetic samples were completed in the field or the core repository. The exceptions were cases in which material chosen for sampling was indurated to the point that a rock saw was required to cut uniform samples of the required dimensions. Normally, paleomagnetic samples were carved at the outcrop or core repository using a stainless steel knife. At the outcrop, samples were carved after hand-tool excavation exposed undisturbed, relatively unweathered, moist sediments. Samples were collected in pairs and placed in clear plastic sample boxes that are 1.7 centimeters on a side. Field orientation measurements relative to horizontal and magnetic north were made using a pocket transit and are accurate to approximately 2 degrees. Paleomagnetic samples from core material were collected with their upper surface level. Orientation data, sample identifier, and the fiducial arrow relative to which the azimuth was measured were placed on the "up" side of the sample. The azimuth of samples collected from the core is unknown.

At the conclusion of one day's collection, the samples were covered with a clear casting resin and the sample cubes recapped. The resin hardened and protected the sample material from moisture loss and mechanical disturbance during

handling and shipping. All materials used in collection and preparation are non-magnetic and the samples were protected from exposure to large electrical or magnetic fields and high temperature.

The samples were measured using a three-axis super-conducting rock magnetometer having a sensitivity of 10^{-8} emu/cm³ and were demagnetized progressively in a 400-hertz alternating field (AF). The number of demagnetization levels varied depending on the magnetic coercivity range of the samples; on the average, ten measurements were made per sample (Table 1). The AF demagnetization unit is magnetically shielded and rotates the sample about three orthogonal axes during demagnetization. The results of AF demagnetization provide a basis for evaluating the magnetization of a sample through the relative direction and intensity changes during demagnetization.

All data were recorded and processed during measurement by an on-line computer. The computer is connected to the magnetometer through a signal conditioning interface. The operator, using immediate feedback of the results of a measurement, selects subsequent demagnetization levels so as to optimize the measurements of a particular sample.

The results of the paleomagnetic measurements for each of the 294 samples collected are presented by sample, one page per sample, in the data volume. The data volume is on file at the Basalt Waste Isolation Program Library. These results are given as a numerical listing of magnetization and vector differences, a Zijderveld plot of the stratigraphic magnetization directions, a stereonet plot of the stratigraphic magnetization directions and vector differences, and a plot of normalized magnetic intensity versus demagnetization level. These measurement results are arranged stratigraphically in each section.

The declination, inclination, and intensity of magnetization of the samples from the various sections are plotted as a function of their stratigraphic position on Figures A-1 through A-3 (Appendix). Two samples were collected at each stratigraphic horizon, and on these graphs two measurements are plotted for each sample: the magnetization of the sample prior to AF demagnetization (natural remanent magnetization [NRM]); and the magnetization of the sample after a selected level of demagnetization.

The directions of the magnetization of the various sections are also plotted as a group on Wulff equal-angle stereonet on Figures A-4 through A-7 (Appendix). The directions of magnetization plotted in the upper left corner of these figures display the directions of magnetization of the samples from a particular section prior to their demagnetization; the magnetization directions plotted in the lower right corner display the directions of the same group of samples after their demagnetization.

The selection of a single measurement from the several measurements made on a sample during its demagnetization is based on the relative magnetic direction and intensity changes in the magnetization of the sample during this process. This selection represents an interpretation of the characteristic magnetization of the sample after the removal of secondary or unstable magnetic components acquired after deposition and compaction.

SUMMARY OF PALEOMAGNETIC RESULTS

Parsons Canyon and Ringold Flat Sections

The White Bluffs exposures of the upper Ringold unit were sampled in Parsons Canyon and an unnamed canyon adjacent to Ringold Flat. The location of these sections and the location

of the section sampled for the WPPSS study are shown on Figures 1 and 2. It was necessary to sample along two traverses to obtain samples throughout the upper Ringold unit. This section extends from the top of the middle Ringold conglomerate up into the caliche zone and loess deposits that cap the Ringold Formation at this locality. These combined traverses included approximately 130 meters of section and 146 paleomagnetic samples were collected as paired samples from 73 horizons. The lithology of the Ringold Flat and Parsons Canyon sections is combined and represented on Figure 3 and photographs of these sections appear on Figure 4. The magnetization of these combined sections is plotted versus depth on Figure A-1 (Appendix) and the effects of AF demagnetization on the distribution of the directions of magnetization of these samples is displayed on group stereonet plots in Figure A-4 (Appendix).

On the basis of magnetic polarity, the Parsons Canyon and Ringold Flat sections can be divided into three stratigraphic intervals or magnetozones. As can be seen on the virtual geomagnetic pole (VGP) latitude versus depth plot that accompanies the stratigraphic column on Figure 3, the lowest magnetozone extends from the top of the basal conglomerate up through the sand and silt, a distance of about 20 meters. The paleomagnetism of this magnetozone is characterized by normal polarity and moderately stable magnetization. The variations in magnetization of this zone are most probably due to varying degrees of chemical remagnetization through the activity of ground water.

The transition from this basal normal magnetozone to the overlying one is abrupt, and is seen as a polarity transition in a uniform lithology where strata having normal polarity are overlain by strata having reversed polarity. The transition is completed within 25 centimeters. This second zone is approximately 106 meters of strata comprised of sand, sandy

LOCATIONS OF SECTIONS AND CORE
HOLES SAMPLED ON THE HANFORD SITE
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Figure 1
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0 0.5 1 2 MILES

0 0.5 1 2 KILOMETERS

LOCATIONS OF PARSONS CANYON, RINGOLD FLAT,
AND WPPSS STUDY SECTIONS
Rockwell-Ringold Paleomagnetism

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Figure 2

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VGP LATITUDE, MAGNETIC POLARITY, AND LITHOLOGY VERSUS STRATIGRAPHIC HEIGHT AT RINGOLD FLAT-PARSONS CANYON SECTIONS
Rockwell-Ringold Paleomagnetism

(a) Ringold Formation at Parsons Canyon. Diatomite unit is top of section sampled. View is northeast.

(b) Ringold Formation at Ringold Flat. Section sampled extends from diatomite seen at Parsons Canyon through slope-forming units and cliff-forming unit to caliche cap and loess deposits. Note prominent vegetation lines in slope-forming units. View is east.

PHOTOGRAPHS OF PARSONS CANYON
AND RINGOLD FLAT SECTIONS

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Figure 4

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silt, silt, clay, and two prominent diatomite or ash units. Samples from this zone are predominantly reversed, but four horizons in the lower portion yielded samples that have an apparent normal polarity. These horizons are lithologically unique. The four horizons where normal polarities exist in this second magnetozone are centered approximately 30, 58, 74, and 84 meters above the base of the section. These horizons are medium-grained to fine-grained, friable sands. Two horizons, centered at approximately 58 and 74 meters, occur near the base of sand units that overlie silt. At various exposures in the White Bluffs, these two horizons act as aquifers and are prominent as zones of relatively thick vegetation. The apparent normal polarities are probably due to remagnetization by oxidation or chemical precipitation from the ground water activity.

Units of the lower portion of the section weather rapidly forming moderately steep slopes. Because of this, extensive hand-tool excavation was necessary to expose fresh, moist sediments for sampling. The sediments in this zone are characteristically massive; very few bedding planes were noted. Silt units that were encountered invariably exhibited deep blocky weathering, contained clay slicks, and plant roots were common. Several of these silt units were resampled after a greater excavation of the talus and weathered sediment at that horizon. Measurement of the less-weathered samples often indicated a reversed polarity, whereas the initial collection had yielded samples having normal or questionable polarity.

The upper portion of the reversed second magnetozone coincides with the cliff-forming silts and clays and the overlying indurated cross-bedded sands. These beds span approximately 40 meters of section. The direction of magnetization from paired samples and samples from adjacent horizons is remarkably consistent. The upper cross-bedded sands had NRM directions that were, in some cases, divergent from their

direction after AF demagnetization. These upper cross-bedded sands are slightly oxidized, and this oxidation may account for the secondary magnetic component, which was in a different direction and probably acquired in a normal field. This component was easily removed during AF demagnetization.

The lithology of the highest magnetozone in the Ringold Flat section is thick caliche and overlying loess. The polarity of samples from both these units is normal.

Taunton Section

Twenty-four paleomagnetic samples from 12 horizons were collected near the Taunton section in a preliminary effort to compare the magnetostratigraphy of the White Bluffs section with sections outside the Pasco Basin. The 54-meter-thick exposure sampled is approximately 1.75 kilometers west of the Taunton Substation along the Chicago, Milwaukee, St. Paul, and Pacific Railroad right-of-way (Figures 1 and 5). It is situated on what appears to be a tilted, slightly folded slump block of a landslide that is approximately 22 square kilometers in areal extent. At this location, the strata are not internally faulted and the dips on bedding range from 25 degrees north on the southern side of the exposure sampled to 15 degrees north on the northern side (Figure 6[a]). The orientation of the samples from this section has been corrected for this tilting.

The magnetization of the samples from the Taunton section plotted versus stratigraphic position are presented in Figure A-2 (Appendix). The directions of magnetization of these samples are also plotted as a group, before and after AF demagnetization, on stereonet in Figure A-5 (Appendix).

LOCATION OF THE TAUNTON SECTION

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Figure 5

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(a) Ringold Formation exposure sampled near Taunton. Section extends from lowest exposure of slope-facing units up through cliff-forming unit to top of exposure. View is east.

(b) Ringold Formation exposure sampled near Moses Lake in Lind Coulee. Base of section is in oxidized sand unit on creek bank; top of section is at caliche cap. View is northeast.

PHOTOGRAPHS OF TAUNTON
AND MOSES LAKE SECTIONS

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Figure 6

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The sand and silty-sand lithology and reversed magnetic polarity (Figure 7) of the section sampled at Taunton is similar to those of the upper part of the sequence of sediments seen at Ringold Flat. After AF demagnetization, the magnetization directions of samples from this section showed good consistency between samples from the same horizon and adjacent horizons. Samples collected at two adjacent horizons, Rl03 and Rl10, do not have the reversed polarities of the other samples from this section. The sediment at horizons Rl03 and Rl10 is brown sandy silt, and is similar to sediments sampled above and below that had reversed polarity. There is no clear association with different degrees of oxidation or association with ground water at these and adjacent horizons, as there was at the four normal horizons in the second magnetozone at the Parsons Canyon-Ringold Flat sections. It is not possible to evaluate, using the information available, whether or not the normal polarity of these two horizons represents secondary magnetization or the original field polarity at the time of deposition.

Moses Lake Section

The exposures sampled near Moses Lake (Figure 8) are on the banks of the stream in Lind Coulee and on a nearby landslide scarp that exposes fresh sediment. The creek in Lind Coulee carries irrigation waste water and the landslide appears to have resulted from the undercutting of the creek bank. Based on the regional elevation trend and geographic location, it was assumed that these sediments are part of the upper Ringold unit, yet the strata seen in this exposure are unlike those seen at the upper part of the upper Ringold unit at the White Bluffs. Several beds are very fossiliferous, containing fish vertebra, gastropod and pelecypod tests, and possibly some mammalian material. The sediment at this locality is generally unweathered, although hand-tool excavation was necessary at several of the highest horizons to expose moist

VGP LATITUDE, MAGNETIC POLARITY, AND
LITHOLOGY VERSUS STRATIGRAPHIC HEIGHT
AT TAUNTON SECTION
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Figure 7

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LOCATION OF THE MOSES LAKE SECTION

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Figure 8

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sediment. The nine horizons sampled at this exposure span 28 meters of section (Figure 9[a]). The magnetization of the samples from the Moses Lake section versus stratigraphic position is plotted on Figure A-3(a) (Appendix). The directions of magnetization of these samples are also plotted as a group, before and after AF demagnetization, on stereonet in Figure A-5 (Appendix).

On the basis of the normal magnetic polarity and the lithology of the section sampled in Lind Coulee, this section can be divided into two roughly equal portions. The five horizons sampled in the lower of these two portions yielded samples having a steep, positively inclined magnetization and good consistency in the magnetization of samples from the same horizon. Samples from the four horizons in the upper portion of this section were also predominantly normal in polarity, but samples from some horizons contained magnetic components having reversed magnetic polarity.

In the lower portion of this section, horizons R201 (the lowest) to R203 were taken from oxidized, moderately indurated medium-grained sands along the creek bank. The magnetization of all these samples is in a low-coercivity region. Coercivity is a measure of the strength of the demagnetization field. The upper two horizons sampled in the lower portion of the section, R204 and R205, were taken from a massive, well-indurated silty clay bed. Much of the magnetization of these clay samples is in the intermediate- and high-coercivity ranges. The nature of the contact between the silty clay and the underlying sand is unknown, for it is covered by thick talus and the toe of the landslide.

The sequence of sediments overlying the massive silty clay unit is included in the upper portion of the Moses Lake section. It is a series of as many as seven paleosols, sand, and a thick caliche cap. The normal magnetization of samples

PALEOMAGNETIC LEGEND

VGP LATITUDE, MAGNETIC POLARITY, AND LITHOLOGY VERSUS STRATIGRAPHIC HEIGHT AT MOSES LAKE AND NORTHERN WHITE BLUFFS SECTIONS

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Figure 9

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from these beds changed in direction during AF demagnetization due to the removal of a magnetic component that varies in direction and intensity. The low-coercivity components of the samples from horizon R207 contained a magnetization that is negatively inclined and the higher coercivity components had positive inclination. The opposite was found in the magnetization of the samples from horizon R209; the magnetization of the low-coercivity component was typical of that produced in a normal field and the high-coercivity magnetization was reversed in polarity. Samples from horizons R206 and R208 also exhibited changes in magnetic direction during demagnetization. Most of the magnetization is in regions of low coercivity, however, and is of normal polarity. There are several possible explanations for the magnetization of this paleosol sequence. The most likely explanation since the samples do not appear to be highly oxidized suggests that a polarity transition from a normal field to a reversed field occurred during the formation of the higher soil horizons. This transition may have produced the low-coercivity reversed overprint seen in the lower paleosols. This magnetization could also be due to viscous magnetization acquired in the earth's present field, although no viscous magnetization was apparent during measurement of these samples.

Northern White Bluffs Section

Sampling was performed in the northern White Bluffs (Figure 10) to aid in evaluating the age of the Moses Lake section relative to the Ringold Flat section. The regional elevation trend and geographic location suggest that units younger than those might be exposed in the northern White Bluffs.

Sampling was restricted to the upper 20 meters of the White Bluffs exposed at this locality because the base of this section was an indurated cliff-forming silty clay that is very

0 0.5 1 2 MILES

0 0.5 1 2 KILOMETERS

LOCATION OF THE NORTHERN
WHITE BLUFFS SECTION

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Figure 10

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similar to that sampled at Ringold Flat (Figures 9[b], and 11). This silty clay unit is capped by a caliche-cemented conglomerate. The caliche at this location is divided into two zones by a thin loess and fine sand interbed that is approximately 1/2 meter thick. At this locality, the upper caliche is capped by 2 to 3 meters of loess-like deposits (Figure 11[b]). This loess deposit has the density and texture typical of wind-borne detritus; however, the bedding and structure suggest reworking by water. The magnetic inclination, declination, and intensity of the northern White Bluffs samples is plotted relative to their stratigraphic position on Figure A-3(b) (Appendix). The directions of magnetization of these samples are also plotted as a group, before and after AF cleaning, on stereonet in Figure A-6 (Appendix).

A reversed-to-normal polarity transition occurs at the top of the Ringold Flat section. The polarity of the samples collected from the lowest four horizons within the silty clay at this locality is reversed; at three of these horizons, the consistency of the magnetization between samples from the same horizons is good. Since the overlying caliche zone is predominantly composed of basalt cobbles and pebbles, it was not sampled. Samples were collected from the sand bed within the caliche and they had a consistent normal magnetic polarity.

Multiple components of magnetization exist in the samples collected at three of the six horizons sampled at the northern White Bluffs section. Samples from adjacent horizons in the silty clay units, R303 and R304, had magnetic behavior indicative of multiple magnetic components of opposite polarity. The higher coercivity components of samples from both these horizons are reversed; in the samples from horizon R304, this reversed component accounts for the largest fraction of the NRM. Samples from the third horizon (R303)

(a) Ringold Formation sampled at northern White Bluffs. Section sampled extends from diatomite-ash unit up to caliche cap. View is east.

(b) Loess unit, which overlies caliche cap, sampled at northern White Bluffs. Draw in background is head of canyon shown in (a). View is south.

PHOTOGRAPHS OF NORTHERN
WHITE BLUFFS SECTION

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Figure 11

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that had multiple components of magnetization were collected from the loess deposits that overlie the caliche zone. The polarity of this horizon is questionable because the magnetic inclinations of its samples are shallow, but they do possess a low-coercivity magnetic component that is negatively inclined.

Samples Collected From Drill Core

The magnetic polarities observed during AF demagnetization of the samples collected from core recovered from six drill holes on the Hanford Site is summarized by drill hole in Tables 2 through 7. In these tables, the apparent polarity of the magnetization in the low-, intermediate-, and high-coercivity regions of a sample is assessed. The low-coercivity region is defined for this analysis as the fraction of magnetization removed during treatment in a demagnetization field of less than approximately 150 oersteds; intermediate-coercivity corresponds to magnetization removed in fields greater than 150 oersteds and less than approximately 500 oersteds; magnetization removed during treatment in a field greater than 500 oersteds is from the high-coercivity region. Magnetic polarity was assigned to these coercivity regions on the basis of the sign of the inclination of the magnetic difference vector. If the inclination of the magnetization removed was positive, a normal polarity was assigned; if negative, a reversed polarity was assigned. If the vector difference inclination was less than 20 degrees, the polarity was labeled as shallow. No polarity assignment for the high- or intermediate-coercivity regions of some samples indicates that these samples had only a small fraction of their magnetization in these coercivity regions.

The polarity of a sample horizon was assessed on the basis of the magnetic polarity observed in the various coercivity regions of the sample pair from that horizon. The most common

TABLE 2

PALEOMAGNETIC RESULTS
OF MEASUREMENTS ON SAMPLES FROM
HOLE DH-6

Sample Number	Polarity of Coercivity Regions ¹			Individual Sample Horizon Polarity ²	Sample Lithology
	Low	Intermediate	High		
91.0 A B	Shallow Normal	Shallow Shallow		Questionable ³	Medium sand
107.5 A B	Normal Normal	Normal Normal	Normal Normal	Normal	Silt
114.0 A B	Normal Normal	Normal Normal	Normal	Normal	Silt
122.5 A B	Normal	Shallow	Shallow	Questionable	Fine sand
132.0 A B	Reversed Reversed	Normal Normal	Normal Normal	Normal?	Silt
133.0 A B	Reversed Reversed	Normal Normal	Normal Normal	Normal?	Silt
372.0 A B	Normal Normal	Normal Normal		Normal	Medium sand
380.3 A B	Normal Normal			Normal	Medium sand
413.0 A B	Reversed Reversed	Normal Reversed		Reversed	Silt
429.6 A B	Normal Normal	Reversed Reversed	Reversed	Reversed	Silt
467.8 A B	Normal Normal	Normal Normal	Reversed	Normal?	Medium sand

Note: See footnote explanations following Table 7.

TABLE 3
PALEOMAGNETIC RESULTS
OF MEASUREMENTS ON SAMPLES FROM
HOLE DH-7

<u>Sample Number</u>	<u>Polarity of Coercivity Regions¹</u>			<u>Individual Sample Horizon Polarity²</u>	<u>Sample Lithology</u>
	<u>Low</u>	<u>Intermediate</u>	<u>High</u>		
148.5 A	Normal	Normal	Normal	Normal	Silt
B	Normal	Normal	Normal		
155.0 A	Normal	Normal	Normal	Normal	Silt
B	Normal	Normal	Normal		
168.5 A	Normal	Reversed	Reversed	Reversed	Fine sand
B	Normal	Reversed?			
283.0 A	Normal	Reversed		Reversed?	Medium sand
B	Normal	Reversed	Normal		
292.5 A	?			Questionable ³	Medium sand
B	?				
336.5 A	Reversed	Reversed	Reversed	Reversed	Fine sand
B	Reversed	Reversed	Reversed		
458.5 A	Reversed	Reversed	Reversed	Reversed	Clay
B	Reversed	Reversed	Reversed		
462.0 A	Normal	Reversed	Reversed	Reversed	Silt
B	Normal	Reversed	Reversed		
468.5 A	Reversed			Reversed	Silt
B	Reversed				
474.0 A	Normal	Normal		Reversed?	Silt
B	Normal	Reversed			
481.5 A	Normal	Normal		Normal	Silt
B	Normal	Normal			

Note: See footnote explanations following Table 7.

TABLE 4

PALEOMAGNETIC RESULTS
OF MEASUREMENTS ON SAMPLES FROM
HOLE DH-9b

<u>Sample Number</u>	Polarity of Coercivity Regions ¹			<u>Individual Sample Horizon Polarity²</u>	<u>Sample Lithology</u>
	<u>Low</u>	<u>Intermediate</u>	<u>High</u>		
266.5 A B	Normal Reversed			Questionable ³	Silt
277.0 A B	Normal Normal			Normal	Fine sand
284.0 A B	Normal Reversed	Normal		Normal?	Medium sand
320.6 A B	Reversed Normal	Reversed Reversed		Reversed	Silt

Note: See footnote explanations following Table 7.

TABLE 5
PALEOMAGNETIC RESULTS
OF MEASUREMENTS ON SAMPLES FROM
HOLE DH-11

<u>Sample Number</u>	<u>Polarity of Coercivity Regions¹</u>			<u>Individual Sample Horizon Polarity²</u>	<u>Sample Lithology</u>
	<u>Low</u>	<u>Intermediate</u>	<u>High</u>		
145.8 A	Reversed	Normal	Normal	Normal	Silt
B	Normal	Normal	Normal		
149.5 A	Normal	Normal	Normal	Normal	Silt
B	Normal	Normal	Normal		
152.5 A	Normal	Normal	Normal	Normal	Silt
B	Normal	Normal	Normal		
162.0 A	Normal	Normal		Normal?	Medium sand
B	Reversed				
167.0 A	Normal	Reversed		Reversed	Medium sand
B	Normal	Reversed			
170.0 A	Normal	Normal		Normal	Medium sand
B	Normal	Normal			
175.0 A	Normal	Reversed	Reversed	Reversed	Clay
B	Reversed	Reversed			
178.5 A	Normal	Reversed	Reversed	Reversed	Silt
B	Normal	Reversed	Reversed		

Note: See footnote explanations following Table 7.

TABLE 6
PALEOMAGNETIC RESULTS
OF MEASUREMENTS ON SAMPLES FROM
HOLE DH-13

<u>Sample Number</u>	<u>Polarity of Coercivity Regions¹</u>			<u>Individual Sample Horizon Polarity²</u>	<u>Sample Lithology</u>
	<u>Low</u>	<u>Intermediate</u>	<u>High</u>		
167.8 A	Reversed	Reversed	Reversed	Reversed	Fine sand
B	Reversed	Reversed	Reversed		
172.0 A	Normal	Normal	Normal	Normal	Fine sand
B	Normal	Normal	Normal		
176.6 A	Normal	Normal	Reversed?	Normal	Silt
B	Normal	Normal	Reversed?		
183.3 A	Normal	Reversed		Reversed	Caliche
B	Normal	Reversed			
183.5 A	Normal	Shallow		Reversed	Caliche
B	Normal	Reversed			

Note: See footnote explanations following Table 7.

TABLE 7
PALEOMAGNETIC RESULTS
OF MEASUREMENTS ON SAMPLES FROM
HOLE DH-17

Sample Number	Polarity of Coercivity Regions ¹			Individual Sample Horizon Polarity ²	Sample Lithology
	Low	Intermediate	High		
380.8 A	Normal	Reversed		Reversed	Silt
B	Reversed	Reversed	Reversed		
387.5 A	Normal	Reversed		Reversed	Silt
B	Reversed	Reversed			
392.5 A	Reversed	Reversed		Reversed	Silt
B	Normal	Reversed			
399.0 A	Reversed	Reversed		Reversed	Silt
B	Reversed				
406.5 A	Reversed	Normal		Normal?	Silt
B	Normal	Normal			
414.5 A	Reversed	Reversed?		Reversed?	Silt
B	Reversed	Reversed?			
424.5 A	Reversed	Normal		Normal?	Silt
B	Reversed	Normal	Normal		
429.5 A	Reversed	Reversed?		Reversed	Fine sand
B	Reversed	Reversed			

Note: See footnote explanations following Table 7.

EXPLANATIONS OF TABLES 2 THROUGH 7

- ¹These polarity assignments are based on the inclination of the magnetization that was removed from the low-, intermediate-, and high-coercivity regions of a sample. Low coercivity is defined as magnetization removed during a peak field less than approximately 150 oersteds, intermediate coercivity corresponds to magnetization removed in peak fields greater than 150 oersteds and less than approximately 500 oersteds, and high coercivity corresponds to magnetization removed in peak fields greater than 500 oersteds.
- ²These polarity assignments are based on the magnetic polarities observed in the various coercivity regions of the sample pair.
- ³An assignment of Questionable is made when the magnetization observed in paired samples is indicative of neither normal nor reversed polarity, or the polarity of the sample pair is contradictory.

source of post-depositional magnetization is the formation of certain iron oxides by chemical activation. Except in the case of hematite formation, this activity is most likely to affect the soft or low-coercivity magnetic components. Thus, in the absence of secondary hematite, higher coercivity components are more likely to reflect the magnetic field direction that existed during the time of deposition. For this reason, greater emphasis is placed on the magnetic polarity contained in the higher coercivity regions when assigning polarity to a horizon.

Due to the long storage time, some core material may contain viscous magnetization. Samples from this material often have substantial low-coercivity magnetic components, poor consistency in the magnetization of paired samples, and poor consistency in the direction of magnetization between adjacent sample horizons.

Samples taken from core recovered from holes DH-11 and DH-13 and the shallower depths of holes DH-6 and DH-7 are from strata near the probable contact of the upper and middle Ringold units. Figures 12 and 13 show the mixed polarities encountered in this interval. At holes DH-11 and DH-13, the shallow samples were predominantly normal and the lower samples reversed. The shallow horizons sampled in holes DH-6 and DH-7 are predominantly of normal polarity.

The horizons sampled at greater depth in holes DH-6 and DH-7 are within the middle and lower Ringold unit; the polarity of these samples is predominantly reversed. Samples collected from the lower Ringold unit at hole DH-17 (Figure 14) are also predominantly reversed. Samples of the Ringold Formation, at four horizons in hole DH-9b, at the eastern edge of the Hanford Site, have mixed polarity. The samples from the

LITHOLOGY

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HEIGHT ABOVE
MEAN SEA LEVEL
meters feet

180
170
160
150
140
130
120
110
100
90
80
70
60
50
150

HOLE DH-7

TOTAL DEPTH IS
39.9 METERS ABOVE
MEAN SEA LEVEL

HOLE DH-13

LITHOLOGY

TOTAL DEPTH IS
138.4 METERS ABOVE
MEAN SEA LEVEL

PALEOMAGNETIC LEGEND

LITHOLOGIC LEGEND

* DEPTH BELOW GROUND SURFACE IN FEET

PALEOMAGNETIC LEGEND

LINES CONNECTING DATA POINTS ARE AVERAGE INCLINATION

LITHOLOGIC LEGEND

* DEPTH BELOW GROUND SURFACE IN FEET

INCLINATION, MAGNETIC POLARITY,
AND LITHOLOGY VERSUS DEPTH
AT CORE HOLES DH-17 AND DH-9b
Rockwell-Ringold Paleomagnetism

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Figure 14
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highest horizon sampled in hole DH-9b have contradictory polarities; samples from the next two lower horizons have normal polarities, and the lowest horizon sampled is reversed.

DISCUSSION OF THE MAGNETOSTRATIGRAPHY

The magnetostratigraphy of the upper Ringold unit seen at the WPPSS section is essentially duplicated at the Parsons Canyon-Ringold Flat sections. Differences in the magnetization of these two sections are mainly due to a greater density of sample horizons at the Parsons Canyon-Ringold Flat sections. The central portion of the Parsons Canyon-Ringold Flat sections is magnetically reversed and the transition to the zones of normal polarity at its base and top occurs abruptly. The "noise" seen in the basal portion of the reversed section often exhibits transitional polarity and probably is an effect of chemical oxidation produced by the activities of ground water.

Like the Ringold Flat section, the majority of the samples collected at the Taunton section had reversed polarity. The character of the magnetization seen in the indurated silty clay in the upper portion of the Taunton section is also similar to that observed in the cliff-forming units at Ringold Flat; the agreement of the magnetization between samples from the same horizon and the agreement in the magnetization between the adjacent horizons sampled is good.

As stated in the Summary of Paleomagnetic Results, it is difficult to lithologically correlate the Moses Lake section with the type section in the White Bluffs. Grolier and Bingham (1978) describe the oxidized sand unit at the Moses Lake site as a brown tuffaceous sand and note that locally it "rests unconformably atop the Roza member" of the Yakima Basalt. They also note several other sites where a brown

tuffaceous sand facies crops out in areas underlain by the cliff-forming silty clays of the White Bluffs. Although a brown tuffaceous sand exists at the Ringold Flat traverse, it cannot be confidently inferred from the occurrence of these brown sands that strata younger than those seen below the caliche cap in the White Bluffs have been sampled below the caliche cap at the Moses Lake site. If this were the case, the magnetostratigraphy of the upper Ringold Formation would be extended to include the normal zone seen at the Moses Lake section and an overlying reversed zone that may exist at the top of the section sampled there. More detailed stratigraphic correlations, as well as more paleomagnetic data between these exposures, are necessary to verify or negate this hypothesis.

The magnetization of the units of the Ringold Formation sampled at the northern White Bluffs locality agrees with the magnetostratigraphy of similar units sampled at the Ringold Flat section. The shallow magnetization seen in the loess-like deposits at the northern White Bluffs does not agree with the normal polarity observed in similar deposits at Ringold Flat. This inconsistency suggests that these loess units may locally transgress a polarity transition and are thus potentially useful in studying the chronology of the upper Ringold unit.

A reversed-to-normal transition in the core holes is most clearly seen in the magnetization of the samples collected from hole DH-11, drilled in the central part of the Hanford Site, where sampled horizons are closely spaced and the interval sampled is relatively extensive. A time-stratigraphic correlation between the normal magnetozones observed at Parsons Canyon and the normal polarity observed in DH-11 might be made if this magnetozones could be duplicated in core samples from a hole nearer the type locality in the White Bluffs.

Much of the middle Ringold Formation can not be subjected to paleomagnetic sampling due to the prevalence of conglomerate in this unit. The few samples taken from sand lenses in the middle Ringold Formation had mixed magnetic polarities. With more paleomagnetic data from the sand lenses in the middle Ringold unit, it may be possible to relate the predominantly reversed polarity of samples from the lower Ringold unit to the reversed trend seen near the top of the middle Ringold unit. Sampling at closely spaced intervals from core that is freshly cut would also help in assessing the magnetization observed in the sand units of the lower and middle units of the Ringold Formation. These samples might also enable correlation of magnetostratigraphic units between drill holes.

The normal and reversed polarity of the sections sampled, in conjunction with paleontological and stratigraphic evidence, make it possible to bound the age of the Ringold Formation. Different aged units having the same polarity cannot be distinguished from one another on the basis of magnetic polarity alone. The relative length of time suggested by the thickness of the rock record can be used, however, to evaluate whether a predominantly reversed or normal section is from a reversed or normal magnetic epoch or a shorter polarity event (Figure 15). The approximately 100 meter thick magnetic reversed sequence in the upper Ringold unit may suggest a reversed magnetic epoch, if this section represents at least 100,000 to 200,000 years. The typical length of a polarity event is only several tens of thousands of years to approximately 150,000 years, with a few events as long as 200,000 years. Evaluation of sedimentation rates in relation to the duration and estimated stratigraphic thickness of polarity zones is not well enough constrained, based on available data, to provide conclusive evidence of the age of this reversed section.

EXPLANATION

Normal Polarity

Reversed Polarity

MAGNETIC POLARITY SEQUENCE
FROM FIVE MILLION YEARS TO PRESENT
Rockwell-Ringold Paleomagnetism

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Figure 15

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Evidence which might bracket the age of this magnetostratigraphic sequence includes paleontologic evidence from the upper Ringold unit (Gustafson, 1978) which suggests that the unit is older than the oldest age of the Matuyama Epoch. The late Miocene age of the underlying basalts makes it unlikely that the upper Ringold unit is of the magnetically reversed Epoch 6 age (5.6 to 6.4 million years). These lines of evidence suggest that the reversed polarity of the upper Ringold unit is Gilbert Epoch in age (Figure 15). The magnetostratigraphy or other evidence from the lower and middle Ringold units may provide the data required to evaluate whether or not this reversed upper Ringold unit is early or late Gilbert Epoch in age.

CONCLUSIONS

- 1) The magnetostratigraphy of the upper Ringold unit exposed in the White Bluffs at the Parsons Canyon-Ringold Flat sections has a 20-meter-thick section of normal magnetic polarity at its base and is overlain by approximately 110 meters of section having reversed magnetic polarity. The caliche and loess that overlie this section have a normal magnetic polarity.
- 2) The samples from the Ringold Formation exposed outside the Pasco Basin have normal and reversed magnetic polarity, magnetization that has predominantly consistent directions between paired samples, and magnetization directions that are generally consistent between adjacent sample horizons. They are thus favorable for paleomagnetic analysis.
- 3) The samples from the subsurface in the Pasco Basin have normal and reversed magnetic polarity, and magnetization that has poor consistency between magnetization directions of paired samples and adjacent horizons. A dense sample spacing

and/or fresh core material may be required to select favorable material for paleomagnetic analysis.

4) The polarity sequence at the Ringold Flat-Parsons Canyon sections and evidence of reversals in other parts of the Ringold Formation suggest that correlation of these units using paleomagnetism is possible.

5) The reversed magnetic polarity sequence of the upper Ringold unit, if assumed to represent a period longer than 100,000 to 200,000 years, suggests, in conjunction with paleontological evidence, that this reversed sequence is within the Gilbert Reversed Epoch. The Gilbert Reversed Epoch is approximately 3.32 to 5.12 million years of age.

REFERENCES

- Grolier, M. J., and Bingham, J. W., 1978, Geology of parts of Grant, Adams, and Franklin counties, east-central Washington: State of Washington Department of Natural Resources, Division of Geology and Earth Resources, Bulletin No. 71.
- Gustafson, E. P., 1978, The vertebrate faunas of the Pliocene Ringold Formation, south-central Washington: Museum of Natural History, University of Oregon, Bulletin No. 25, 62 p.
- Newcomb, R. C., 1958, Ringold Formation of Pleistocene age in type locality, the White Bluffs, Washington: American Journal of Science, v. 256, p. 328-340.
- Woodward-Clyde Consultants, 1979, Paleomagnetic measurements of the Ringold Formation and loess units near Hanford, Washington and evaluation of age dating potential of Quaternary deposits near Hanford, Washington, prepared for United Engineers and Constructors, Inc., 33 p.

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APPENDIX

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APPENDIX TABLE

A-1	Mean paleomagnetic directions of samples from the Parsons Canyon-Ringold Flat, Taunton, Moses Lake, and northern White Bluffs sections	A-8
-----	--	-----

NRM

SELECTED AF
DEMAGNETIZATION LEVEL

LINES CONNECTING DATA
POINTS ARE AVERAGE VALUES

DECLINATION, INCLINATION, AND INTENSITY OF
MAGNETIZATION VERSUS STRATIGRAPHIC HEIGHT
AT RINGOLD FLAT-PARSONS CANYON SECTIONS
Rockwell-Ringold Paleomagnetism

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Figure A-1

Page A-1

DECLINATION, INCLINATION, AND INTENSITY
OF MAGNETIZATION VERSUS STRATIGRAPHIC
HEIGHT AT TAUNTON SECTION
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Figure A-2

Page A-2

(a) MOSES LAKE

(b) NORTHERN WHITE BLUFFS

--- NRM

●/— SELECTED AF DEMAGNETIZATION LEVEL

LINES CONNECTING
DATA POINTS ARE AVERAGE VALUES

DECLINATION, INCLINATION, AND INTENSITY
OF MAGNETIZATION VERSUS STRATIGRAPHIC
HEIGHT AT MOSES LAKE AND NORTHERN
WHITE BLUFFS SECTIONS

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Figure A-3

Page A-3

EXPLANATION

SYMBOLS X AND + ARE THE DIRECTIONS OF THE EARTH'S PRESENT FIELD AND AXIAL DIPOLE FIELD, RESPECTIVELY, AT THE SAMPLING SITES. THE SYMBOL ▲ IS THE MEAN DIRECTION AND THE CIRCLE SURROUNDING IT IS THE ALPHA-95 CIRCLE OF CONFIDENCE. SEE TABLE A-1. PLOTS ARE WULFF (EQUAL ANGLE) STERONETS, SOLID CIRCLES INDICATE LOWER HEMISPHERE, AND OPEN CIRCLES INDICATE UPPER HEMISPHERE.

**STEREONET PLOTS OF
MAGNETIZATION DIRECTIONS AT
RINGOLD FLAT-PARSONS CANYON SECTIONS
Rockwell-Ringold Paleomagnetism**

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Figure A-4

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EXPLANATION

SYMBOLS X AND + ARE THE DIRECTIONS OF THE EARTH'S PRESENT FIELD AND AXIAL DIPOLE FIELD, RESPECTIVELY, AT THE SAMPLING SITES. THE SYMBOL ▲ IS THE MEAN DIRECTION AND THE CIRCLE SURROUNDING IT IS THE ALPHA-95 CIRCLE OF CONFIDENCE. SEE TABLE A-1. PLOTS ARE WULFF (EQUAL ANGLE) STERONETS, SOLID CIRCLES INDICATE LOWER HEMISPHERE, AND OPEN CIRCLES INDICATE UPPER HEMISPHERE.

STEREONET PLOTS OF MAGNETIZATION DIRECTIONS AT TAUNTON SECTION

Rockwell-Ringold Paleomagnetism

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Figure A-5

Page A-5

EXPLANATION

SYMBOLS X AND + ARE THE DIRECTIONS OF THE EARTH'S PRESENT FIELD AND AXIAL DIPOLE FIELD, RESPECTIVELY, AT THE SAMPLING SITES. THE SYMBOL ▲ IS THE MEAN DIRECTION AND THE CIRCLE SURROUNDING IT IS THE ALPHA-95 CIRCLE OF CONFIDENCE. SEE TABLE A-1. PLOTS ARE WULFF (EQUAL ANGLE) STERONETS, SOLID CIRCLES INDICATE LOWER HEMISPHERE, AND OPEN CIRCLES INDICATE UPPER HEMISPHERE.

STEREONET PLOTS OF MAGNETIZATION DIRECTIONS AT MOSES LAKE SECTION

Rockwell-Ringold Paleomagnetism

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Figure A-6

Page A-6

(a) NRM DIRECTIONS

EXPLANATION

SYMBOLS X AND + ARE THE DIRECTIONS OF THE EARTH'S PRESENT FIELD AND AXIAL DIPOLE FIELD, RESPECTIVELY, AT THE SAMPLING SITES. THE SYMBOL ▲ IS THE MEAN DIRECTION AND THE CIRCLE SURROUNDING IT IS THE ALPHA-95 CIRCLE OF CONFIDENCE. SEE TABLE A-1. PLOTS ARE WULFF (EQUAL ANGLE) STERONETS, SOLID CIRCLES INDICATE LOWER HEMISPHERE, AND OPEN CIRCLES INDICATE UPPER HEMISPHERE.

(b) SELECTED AF DEMAGNETIZATION LEVEL DIRECTIONS

STEREONET PLOTS OF MAGNETIZATION DIRECTIONS AT NORTHERN WHITE BLUFFS SECTION

Rockwell-Ringold Paleomagnetism

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Figure A-7

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TABLE A-1

MEAN PALEOMAGNETIC DIRECTIONS¹ OF SAMPLES
FROM THE PARSONS CANYON-RINGOLD FLAT, TAUNTON,
MOSES LAKE, AND NORTHERN WHITE BLUFFS SECTIONS

<u>Section</u>	Mean direction of the NRM		Mean direction at the selected demagnetization level		Alpha-95 circle of confidence	
	<u>Declination</u>	<u>Inclination</u>	<u>Declination</u>	<u>Inclination</u>	<u>NRM</u>	<u>Selected demagnetization level</u>
Parsons Canyon- Ringold Flat	354°	40°	1°	51°	15°	11°
Taunton	220°	68°	320°	78°	36°	24°
Moses Lake	15°	73°	348°	70°	23°	8°
Northern White Bluffs	28°	19°	23°	47°	40°	31°

¹ These values were calculated from data sets derived from the vector directions plotted on Figures A-4 through A-7. By convention, these data sets are obtained by calculating the antipodal magnetic vector directions for samples from reversed magnetozones and combining them with the unaltered magnetic vector directions of samples from normal magnetozones.