Gravity and Aeromagnetic Study of Part of the Yakima River Basin, Washington

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GEOPHYSICAL FIELD INVESTIGATIONS

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A gravity survey of the Toppenish Creek basin and surrounding area in the northwest part of the Columbia River Plateau

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GRAVITY AND AEROMAGNETIC STUDY OF PART OF THE YAKIMA RIVER BASIN, WASHINGTON

By S. L. Robbins, R. J. Burt, and D. O. Gregg

ABSTRACT

A gravity survey of the Toppenish Creek basin, tributary to the Yakima River basin, and surrounding area in the northwest part of the Columbia River Plateau shows a broad, 6-milligal gravity low over much of the basin. The low, which is somewhat smaller than expected, is probably due to about 300 m (1,000 ft) of the Ellensburg Formation and younger sediments that overlie the Yakima Basalt within the structural basin. Analysis of the gravity data suggests that: (1) the Toppenish Creek basin has a relatively flat bottom; (2) the basin is enclosed on the southeast by a broad, buried ridge between Toppenish Ridge and Snipes Mountain; (3) several nearby valley areas contain very little sediment; (4) the thickness of basalts within the study area varies considerably; and (5) as many as four small silicic volcanic cones of pumicite deposits may be buried within the younger Yakima Basalt along a possible north-south fracture zone. Differences in pattern between the main part of Toppenish Creek basin and the shallow valley areas on the aeromagnetic map lend support to the gravity interpretation.

INTRODUCTION

The Yakima River basin is in south-central Washington in the northwest part of the Columbia River Plateau. The part of this basin covered by gravity survey (fig. 1) (principally the Toppenish Creek basin) lies between Naches Valley on the north, Satus Creek on the south, the foothills of the Cascade Range on the west, and the town of Sunnyside on the east. The survey was made in the fall of 1971 in conjunction with an ongoing comprehensive water-resources study of the Yakima Indian Reservation carried out by the U.S. Geological Survey.

In the central part of the Toppenish Creek basin, no wells penetrate the entire thickness of sedimentary rocks belonging to the Ellensburg Formation, which mostly overlies basalt of the Columbia River Group. No other data were previously available to indicate the thickness of the Ellensburg Formation or the configuration of its lower surface. The primary purpose of the gravity survey was to determine both the configuration of the upper surface of Columbia River basalt within the Toppenish Creek basin and the thickness of the water-bearing sedimentary deposits overlying the basalt. Without this information, an appraisal of the aquifer system and development of computerized management models of the system could be based only on a hypothetical projection of the basalt surface from the ridges bordering the basin.

We thank Professor Z. F. Daneš and the University of Puget Sound in Tacoma, Wash., for gravity base station information and for the loan of a Worden gravity meter. Elmer Hauer and the U.S. Air Force Aeronautical Chart and Information Center in St. Louis, Mo., provided us with gravity station data and elevation data. The complete gamma-gamma log for Rattlesnake Hills well No. 1 was graciously provided by D. J. Brown of the Atlantic Richfield Hanford Company.

GEOLOGIC SETTING

The Yakima Basalt of the Columbia River Group and the sedimentary Ellensburg Formation, both of middle Tertiary age, underlie most of the area covered by this report. Older Tertiary volcanic rocks possibly occur beneath the Yakima Basalt in this area (Brown, 1970, p. 180), but they do not crop out. A tongue of Quaternary andesitic lava forms the southwest side of the Naches River valley in the northern part of the map area. The Cascade Range to the west is underlain chiefly by Tertiary igneous and metamorphic rocks.

Regional folding during the Pliocene Epoch warped the basalt and the interlayered and overlying Ellensburg Formation into a series of east-trending anticlinal ridges. From north to south these ridges include Cowiche Mountain, Ahtanum Ridge, and Toppenish Ridge. The Ahtanum Ridge anticline continues east of Union Gap as the Rattlesnake Hills anticline. These anticlinal ridges are generally asymmetrical, with steep slopes on the north and gentler slopes on the south. During the folding, the ancestral Yakima River continued its southeasterly course, bisecting the uplifting ridges and forming steep-walled canyons, such as Union Gap. Most structures in the region trend east-west, except for the northeast-trending ridge flanking the southwest side of Medicine Valley and the east-southeast-trending Sniper Mountain between Granges and Sunnyside. The major ridges are separated by wide synclinal valleys, the structural bottoms of which are partly filled by the Ellensburg Formation, alluvium, and lacustrine silt.

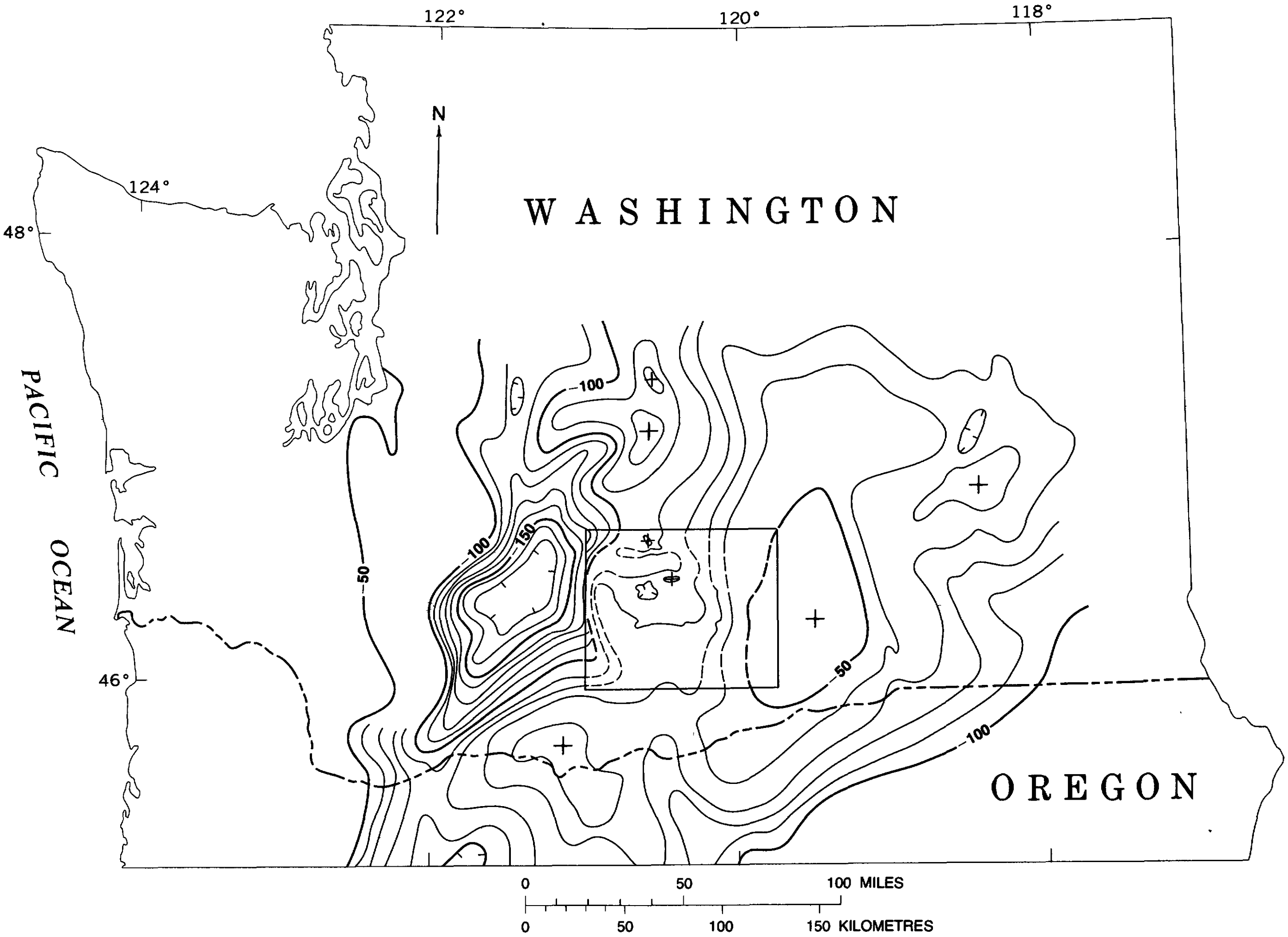

FIGURE 1.—Simple Bouguer gravity map of south-central Washington and north-central Oregon from Woollard and Joesting (1964) and outline of area compared in this report with complete Bouguer anomaly values. Contours are labeled at 50-mgal intervals, and selected intermediate contours at 10-mgal intervals. Hachures indicate gravity lows, and plus signs indicate gravity highs.

ROCK UNITS

YAKIMA BASALT

The Yakima Basalt (fig. 2, pl. 1), which comprises the lava flows in the upper part of the Columbia River Group, is exposed on the ridges and underlies all of the other exposed rock formations in the study area. The Yakima, of middle and late Miocene and early Pliocene age (Fiske and others, 1963, p. 63; Snavely and others, 1973), consists of many individual lava flows, several of which have distinctive petrographic characteristics over wide areas of the region. The lowermost named sedimentary deposit interbedded with the flows of the Yakima Basalt is the Vantage Sandstone Member; below this the Yakima is generally undivided because of lithologic similarity between flows and the rarity of thick interbeds of sedimentary rocks. Overlying the Vantage is about 400 m (1,200 ft) of basalt, subdivided into members of the Yakima Basalt. The thickness of these basalt members and interbeds differs from place to place. The upper flows interfinger with sedimentary rocks assigned to the Ellensburg Formation.

In general, the Yakima Basalt is a hard, dense, microcrystalline rock, black or gray on fresh surfaces. Upper parts of flows are vesicular except where eroded; many central parts exhibit columnar, irregular, or platy jointing. Individual flows are a few to more than 30 m (100 ft) thick.

Pre-Vantage interbeds of sedimentary rocks are rare but locally significant. For example, a pumicite deposit, capped by basalt flows tentatively identified as of pre-Vantage Sandstone age by D. A. Swanson (oral commun., 1972) on the basis of chemical characteristics, was found by Burt and Gregg just south of the gravity-surveyed area along Satus Creek adjacent to State Highway 97 in secs. 21, 28, and 33, T. 7 N., and R. 18 E. The pumicite is 30 m (100 ft) thick or more, but the areal extent is unknown. The bulk density of most particles is less than that of water. The deposit grades downward into a well-cemented basaltic conglomerate containing sporadic quartzite pebbles.

The upper members of the Yakima Basalt and associated interbedded sedimentary materials are briefly described in table 1, which shows a composite stratigraphic sequence for the northwest Columbia Plateau.

ELLENSBURG FORMATION

The Ellensburg Formation (fig. 2, pl. 1) of late Miocene and early Pliocene age (Foxworthy, 1962, p. 19; Bingham and Grolier, 1966, p. G3), overlies and is intercalated with upper flows of the Yakima Basalt. The Ellensburg consists of as much as 600 m (2,000 ft) (Bingham and Grolier, 1966, p. G13) of generally poorly sorted, loosely consolidated lacustrine and fluvial sediment derived primarily from upper Miocene and Pliocene volcanic rocks and much older metamorphic rocks of the Cascade Range, as well as from the Yakima Basalt itself. The formation underlies the valley areas and is occasionally exposed on the flanks of the anticlinal ridges, but it has been eroded from the crests of the ridges, exposing the basalt. The top of the Ellensburg Formation is not well defined, as it grades upward into reworked sedimentary deposits.

TIETON ANDESITE

The Tieton Andesite is a tongue of andesitic lava (fig. 2, pl. 1), which overlies the Yakima Basalt and Ellensburg Formation northwest of the city of Yakima. The andesite occupies valleys eroded in the Ellensburg Formation and Yakima Basalt and is of Pleistocene age (Foxworthy, 1962, p. 21). It is lighter in color than the basalt, and porphyritic.

TOUCHET BEDS

The Touchet Beds (fig. 2, pl. 1) (Flint, 1938, p. 493–499) are Pleistocene varved deposits consisting of as much as 11 m (35 ft) of silt and sand. The Touchet covered much of the lowlands below about the 365-m (1,200-ft) elevation level in the Yakima River basin (Laval 1956, p. 91) but has been partly stripped away by the meandering Yakima River and its tributary streams in the central part of the basin.

LOESS

Loess is the wind-deposited silt of Holocene age that forms mounds over much of the upland benches and ridges. The deposit is not differentiated on the geologic map.

ALLUVIUM AND CEMENTED GRAVEL

The alluvium and cemented gravel (fig. 2, pl. 1) consists of gravel, sand, and silt derived primarily from the Ellensburg Formation, the Yakima Basalt, and to a lesser extent from the igneous and metamorphic rocks of the Cascade Range. The alluvium varies in thickness

TABLE 1.—*Composite stratigraphic sequence in the northwestern Columbia Plateau (from Bingham and Grolier, 1966, p. G3)*

SYSTEM	SERIES	GROUP	FORMATION	MEMBER AND BED	LITHOLOGY AND THICKNESS
TERTIARY	Pliocene		Ellensburg Formation	Ellensburg Formation undifferentiated	Ellensburg Formation undifferentiated: 1,800 ft of pebble conglomerate, sand, and mudflows; upper 500 ft basaltic, contains coarse brown sand; remainder andesitic, with beds of fine ash in lower part
	Miocene or Pliocene			Beverly Member	Beverly Member: As much as 300 ft of pumicite, quartzite-bearing conglomerate, and tuffaceous sand, silt, and clay
		Columbia River Group	Yakima Basalt	Saddle Mountains Member	COLUMBIA RIVER GROUP Yakima Basalt: Saddle Mountains Member: One or more basalt flows; total thickness as great as about 400 ft. Basalt is black to light gray, dense, fine to very fine grained; some flows are sparsely porphyritic. Small columns or hackly jointing are common, but some flows are composed of agglomerate or pillows in places
	Miocene			Priest Rapids Member	Priest Rapids Member: Four basalt flows; total thickness as great as 220 ft. Basalt is grayish black where fresh, mottled greenish brown where weathered; coarse grained and nonporphyritic. Very large columns as much as 10 ft in diameter are common
				Quincy Diatomite Bed	Quincy Diatomite Bed: Diatomite as thick as 35 ft; contains a few lenses of silt and clay
				Roza Member	Roza Member: Two basalt flows; total thickness as great as 200 ft. Baselt is dark blue gray or dark reddish gray where fresh; weathers deep red brown; coarse grained and porphyritic. Phenocrysts are not numerous but are present in nearly all outcrops. Phenocrysts are lath shaped and average 1 cm in length. Large columns which break into plates and chips are common
				Frenchman Springs Member	Frenchman Springs Member: As many as six flows; total thickness as great as 375 ft. Basalt is dark gray to black, medium to fine grained and sparsely porphyritic. Phenocrysts are roughly equidimensional, shattered, yellowish white, and average 1 cm in diameter. Some large columns are present, but irregular jointing is common. Pillow zones are common in lowermost flow
				Squaw Creek Diatomite Bed	Squaw Creek Diatomite Bed: Diatomite as thick as 17 ft; grades westward to sandstone, fine conglomerate, siltstone, or clay
				Vantage Sandstone Member	Vantage Sandstone Member: Sandstone, as thick as 35 ft. Blue or green where fresh, pale yellow where weathered. Consists of medium-grained quartz-feldspar-mica sand, or a tuffaceous sand, silt, and clay
				Lower basalt flows	Lower basalt flows: Total thickness generally more than 1,000 ft. Basalt is dark gray, fine grained, and well jointed. Columns 1–2 ft in diameter are common. Pillows and spiracles more common than in overlying basalt members

from a few to many tens of feet and is generally deeper and coarser on the north side of the valleys, where the Yakima River has built up broad, gentle alluvial fans caused by an increase in gradient as the river emerges from the water gaps. The bottom of the alluvium grades into the top of the Ellensburg Formation, making differentiation between the two difficult.

GEOPHYSICAL DATA

A simple Bouguer gravity map of the region surrounding the lower Yakima River basin is shown in figure 1. The complete Bouguer gravity map (fig. 2, pl. 1) is based on observations made at 462 gravity stations, spaced at intervals of 1½–3 km (1–2 mi). LaCoste-Romberg gravity meter G17 was used at 300 of these stations, and LaCoste-Romberg meter G8 was used at another 58 stations. A Worden gravity meter, having a sensitivity of 0.09277 mgal/scale division, was used at 75 stations located in the central part of the basin. The remaining 29 stations were observations from the files of the Aeronautical Chart and Information Center. All of the observed gravity values are relative to an absolute value of 980,617.74 mgals (Z. F. Daneš, written commun., 1971) at a base station in Yakima, Wash.

The data were reduced using the assumed average crustal density of 2.67 g/cm^3. The terrain effect was removed by using the U.S. Coast and Geodetic Survey system (Swick, 1942, p. 67) through Zone F (2.29 km), and the values for zones G through O (166.7 km) were calculated using a computer program described by Plouff (1966). The resultant complete Bouguer anomaly values were contoured at 2-mgal intervals.

The aeromagnetic map (fig. 3, pl. 1) is based on 31 north-south traverses flown in 1959 by the U.S. Geological Survey, using a continuously recording modified AN–ASQ/3A airborne magnetometer. The flight lines are 1.6 km (1.0 mi) apart and 150 m (500 ft) above the ground surface. The map, compiled by Jack Kirby and others with a location error of the flight lines of 0.4 km (±¼ mi), shows variations in the total intensity relative to the International Geomagnetic Reference Field of 1965 (Fabiano and Peddie, 1969).

GRAVITY INTERPRETATION

The interpretations of the gravity anomalies seen in figure 2 (pl. 1) are based on the following assumptions:

1.—The Ellensburg Formation and the other more recent sedimentary deposits, including loess and alluvium, have a combined average density of 2.3 g/cm^3. This assumption is based on (a) models computed to fit Foxworthy's (1962) interpretation of the structure of Ahtanum Valley and sediment thicknesses determined from drill holes in Ahtanum Valley and Toppenish Creek basin, using Bott's (1960) two-dimensional gravity-mass computation computer program for a one-density contrast model (cross section A–A′, fig. 6, pl. 1); and (b) one uncalibrated gamma-gamma log from a well on the north side of Toppenish Creek basin (well No. 5 in fig. 7, pl. 1).

2.—The Yakima Basalt and older basalts that may underlie the Yakima River basin have an average density of 2.8 g/cm^3. This value is based on a gamma-gamma log from Rattlesnake Hills No. 1 (D. J. Brown, written commun., 1971), a 3,248-metre-deep (10,655-ft) well drilled by Standard Oil Company of California in 1957 and 1958 on Rattlesnake Ridge about 10 km (6 mi) to the east of this study area. The well bottomed in basalt of probable Eocene age (Brown, 1970, p. 179), and only about the uppermost 600 to 1,200 m (2,000 to 4,000 ft) of basalt belongs to the Yakima Formation.

3.—The rocks underlying the basalt are unknown as to type and composition but are assumed to have an average crustal density of 2.7 g/cm^3 (Bromery and Snavely, 1964, p. N3).

4.—Most of the "regional" gravity field represents the variation in the total thickness of the basalts, although it could also be caused partly by lithologic changes in the older basement rocks.

In the attempt to determine the "regional" gravity field, upward continuation of the complete Bouguer gravity field (fig. 2, pl. 1) was computed using the method described by Henderson (1960). The computation is basically a low-pass wave number filter equation (Byerly, 1965, p. 283), and the results of this continuation based on a 1.6-km (1.0-mi) grid to an elevation of 5 km (3 mi) above the surface are shown in figure 4 (pl. 1). Computations were also made for elevations of 1.6 and 3.2 km (1 and 2 mi), but the resultant anomaly field was not smooth and appeared still to contain anomalies caused by relatively small shallow sources. The anomalies shown in figure 4, therefore, represent the gravity attractions caused by large deep bodies and quite possibly the bottom configuration of the basalts, although part of the continued gravity field may be due to lithologic differences within the underlying basement rocks. However, the primary focus of this study is the anomalies caused by the shallower bodies overlying or within the Yakima Basalt.

A map of the residual gravity field (fig. 5, pl. 1) was obtained by subtracting the "regional" field (fig. 4) from the Bouguer field (fig. 2). It is assumed that the anomalies seen in this figure are caused by basin fill (Ellensburg Formation and younger sedimentary deposits) and by structural and lithologic differences within the Yakima Basalt. The most significant features are:

1.—Relatively steep gradients on the flanks of the east-west-trending topographic and structural ridges.

2.—A north-northwest-trending gravity high west of Yakima Valley.
3.—A large gravity high centered just south of Ahtanum Ridge in the vicinity of Union Gap and partly within the north end of the Yakima Valley.
4.—Broad gravity lows over most of the valley areas.
5.—A broad gravity high over the Yakima Basalt south of Yakima Valley.

Quantitative interpretation of features 1, 4, and 5 was performed along the north-south cross section A–A′ (fig. 6, pl. 1) using the two-dimensional gravity-interpretation computer program of Talwani, Worgel, and Landisman (1959).

AEROMAGNETIC INTERPRETATION

The interpretation of the aeromagnetic map (fig. 3, pl. 1) is qualitative, based only upon visual comparisons with the gravity anomalies. Aeromagnetic data are not available for the entire area of the gravity survey, but in the area of coverage, the most significant features are (1) magnetic highs over Toppenish and Horse Heaven Ridges (the contours over Ahtanum Ridge are dashed because the flight lines are not continuous over the ridge), and (2) broader features over the rest of the area.

There is a weak northeast-southwest lineation of the magnetic pattern (fig. 3) in much of the Toppenish Creek basin and part of the large area of exposed basalt to the south, but east of this area the pattern appears to be alined northwest-southeast. High-level aeromagnetic data in Swanson (1971) indicate northwest-southeast trends for the entire area. These lineations probably represent both local and regional deformation trends within (or beneath) the basalt, since remanent magnetization vectors in undefined Tertiary rocks are basically the same or opposite to that of the present field of the earth. It is the variations of these vectors with respect to the earth's field that produce anomaly patterns.

STRUCTURAL SIGNIFICANCE OF DATA

Gravity observations in part of the Ahtanum Valley, in which the thickness of sediment fill and configuration of the basin are better defined (Foxworthy, 1962, pl. 1) than in the Toppenish Creek basin, are included in this study so comparisons could be made. About 3 km (2 mi) southeast of the center of the gravity low (fig. 5, pl. 1) the log of well No. 2 (fig. 7, pl. 1) shows that the upper surface of the Yakima Basalt is at a depth of more than 400 m (1,300 ft). At the gravity minimum, the depth is possibly 100 to 130 m (300 to 400 ft) greater, although part or all of this interpreted increase in depth may be due to buried low-density rocks as discussed later in this section. This gravity low is larger than the low over the Toppenish Creek basin, where calculations based on the gravity data show the Ellensburg Formation to be only about 300 m (1,000 ft) thick.

The structural contours on the buried upper surface of the Yakima Basalt within the valley areas (fig. 7) derived from well-log and gravity data indicate that the sediment thickness is quite uniform within the Toppenish Creek basin and that the north and south sides of the basin are bounded by relatively steep slopes. These slopes and the associated ridges are believed by most geologists to have been formed by folding with only minor faulting in some areas (Waters, 1955, p. 666). According to D. A. Swanson (oral commun., 1973), several investigators presently working on the Columbia plateau are suggesting that block faulting and tilting within the basement rocks beneath the basalts may have caused the folding within the basalts and the asymmetry seen in the ridges. Since the basement rocks are probably of only slightly lower density (0.1 g/cm^3) than the basalts, it would be difficult to observe this faulting and tilting in the gravity data.

South of White Swan a 2- to 3-mgal, nearly circular, partly closed gravity low (fig. 5) is located almost wholly within the mapped Yakima Basalt. Because a large landslide (3×3 km, 2×2 mi) has been observed in this area, the low may reflect an area of structural weakness. However, it is equally possible that a different rock type of lower density may be buried beneath the area, for none of the several other smaller landslides in the study area appear to be associated with gravity lows. North of this gravity low, on the north side of Yakima Valley centered along section A–A′ (fig. 6, pl. 1) is a circular low that cannot be entirely attributed to a greater thickness of sedimentary deposits (Ellensburg Formation). Still farther north (fig. 5) are two more circular lows (including part of the Ahtanum Valley low) that, although located over sediments, are difficult to model relative to the surface geology. The circular shape, the north-south alinement, and the proximity of the Yakima Basalt to the gravity lows plus the indication of relatively shallow sources for the 2- to 3-mgal anomalies suggest the presence of local accumulations of low-density rocks covered by the Yakima Basalt and emplaced along a fracture zone. In the Tieton River area, just northwest of our study area, Swanson (1967, p. 1080) has observed cones of intermediate and silicic volcanic rocks of early or middle Miocene age, and such rocks are common along the east part of the Cascade Range. It therefore seems possible that andesitic or dacitic cones or perhaps local pumicite deposits, such as those described earlier along Satus Creek, lie below or interbedded with the younger Yakima Basalt.

The northwest part of the "regional" gravity map (fig. 4, pl. 1) shows a flat gravity field along with the lowest gravity values. Within the study area, the basalt is probably thinnest in the northwest, perhaps as thin as 0.6 to 1.0 km (2,000 to 3,000 ft). However, as the field increases to the south (fig. 6, pl. 1; a minimum depth of 1.0 km was assumed for this computation) and east, the basalt probably exceeds 7 km (4 mi) in thickness, especially to the east of this survey area where there is a very large gravity high (fig. 1). This area is recognized by others as having the thickest sections of basalts within the Columbia River Plateau (Swanson, 1971, p. 3351).

The areas with large gravity highs in figure 5, specifically (1) the long northwest-southeast-trending high southwest of White Swan, (2) the broad high south of Toppenish Ridge, and (3) the large magnitude high just south of Union Gap, are seen as areas of gravity "ridges" on the "regional" map (fig. 4). There are several possible interpretations for these "ridges": the areas may contain thicker sections of basalt; the basalt may be denser than in some of the surrounding areas; dense intrusions may occur beneath the highs; or the "ridges" may result from a combination of these. The northwest-southeast trend of the gravity high southwest of White Swan is similar in direction to structural trends seen in pre-Yakima Basalt rocks by D. A. Swanson (oral commun., 1972) in the Tieton River area which are on strike with this high. The gravity high located just south of Union Gap and Ahtanum Ridge is partly within the northernmost part of Yakima Valley. Possibly, the Yakima River south of the water gap has eroded away some of the southern part of the ridge, leaving this part of the valley with only a very thin layer of fill (fig. 7).

Snipes Mountain has been described by Laval (1966, p. 101) as a "simple doubly-plunging anticline." Analysis of both the gravity field (fig. 5) and the aeromagnetic expression (fig. 3, pl. 1) over this feature support this description, as the anomalies do not seem to extend much beyond the mountain itself. The gravity field (fig. 5) also suggests that Snipes Mountain may be part of the same anticlinal system as Toppenish Ridge, and that the valley sediments southwest of Snipes Mountain are quite thin, perhaps only 30 to 50 m (100 to 150 ft) thick. Both the gravity and magnetic data indicate that the valley on the north side of the mountain contains more sediment (possibly 60 to 90 m, 200 to 300 ft). Thus, the basin part of Toppenish Creek basin may be closed on the southeast, ending along a line between Snipes Mountain and the east end of Toppenish Ridge.

Immediately south of the line between Snipes Mountain and Toppenish Ridge are two very small magnitude gravity lows. These lows suggest shallow basins of about 60 to 100 m (200 to 300 ft) depth that are undulations in the top of the thick Yakima Basalt field between Toppenish Ridge and Horse Heaven Hills and possibly define an eastward extension of the Dry Creek syncline. The aeromagnetic pattern also suggests that the basins are shallow (fig. 3) for the pattern is similar to the rest of the basalt to the south, whereas in the Toppenish Creek basin the much broader pattern reflects a greater depth to the basalt. Toppenish Ridge and the Horse Heaven Hills have anomalies with short wavelength and greater magnitude than the basalt field between these ridges, probably because the airplane was closer to the basalt over the ridges and because the structure within the ridges is more deformed and complex.

Medicine Valley has only a very thin cover of Ellensburg Formation. Figure 5 shows about a 1-mgal flexure, which suggests about 30 to 50 m (100 to 150 ft) of cover. This agrees with the depth at which basalt was penetrated, 33 m (110 ft) in well No. 4 drilled by the U.S. Geological Survey in 1972.

West of the gravity high southwest of White Swan is a gradient that ends in a very large gravity low centered over the Cascade Range west of the study area (fig. 1). The low is probably caused by low-density Pleistocene volcanic rocks and an "acidic batholith" (Daneš, 1969, p. 549).

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