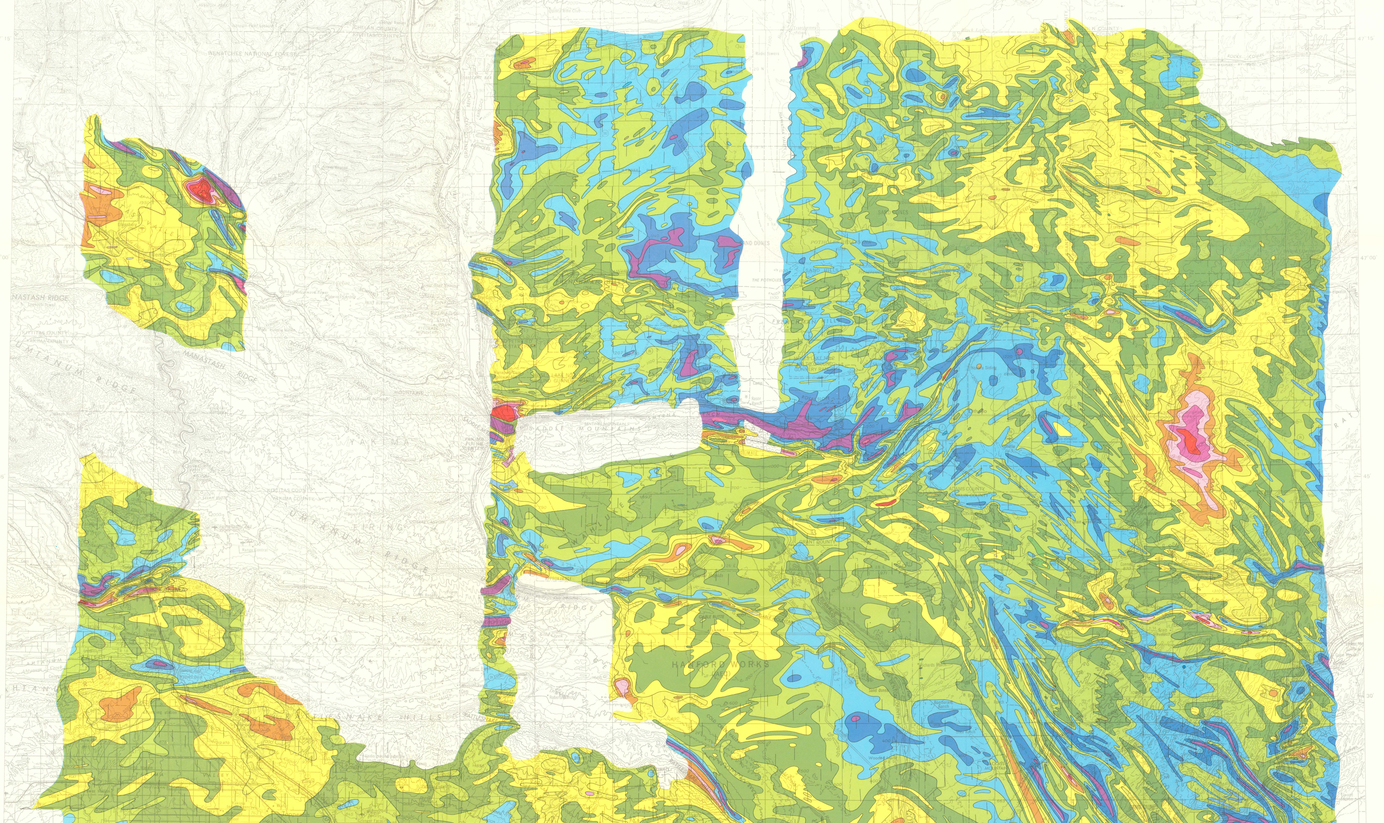
DEPARTMENT OF THE INTERIOR
UNITED STATES GEOLOGICAL SURVEY

GEOPHYSICAL INVESTIGATIONS
MAP GP-917



Base from U. S. Geological Survey
The Dalles, Oregon, Washington 1953;
Pendleton, Oregon, Washington 1953;
Walla Walla, Washington, 1953;
Hanford, Washington, 1957;
Wenatchee, Washington 1957;
Yakima, Washington 1958

Interior—Geological Survey, Reston, Va. — 1979—G76312

Compiled by John R. Kirby and David L. Daniels,1970
Regional gradient removed.

AEROMAGNETIC MAP AND GEOLOGIC INTERPRETATION OF THE WEST-CENTRAL COLUMBIA PLATEAU, WASHINGTON AND ADJACENT OREGON

CONTOUR INTERVAL 100 GAMMAS
FLIGHT ELEVATION 150 METERS

By
Donald A. Swanson, Thomas L. Wright, and Isidore Zietz

1979

ABSTRACT

A low-altitude total-intensity aeromagnetic map of the west-central Columbia Plateau, underlain principally by the Yakima Basalt, shows positive and negative anomalies that stand out from a moderately intensity background reflecting interbedded flows of normal and reversed magnetic polarity. One set of anomalies is related to anticlinal ridges, another follows the trace of faults or inferred faults, and a third set coincides with a swarm of feeder dikes for the Ice Harbor flows of Swanson, Wright, and Helz (1975), the youngest unit of basalt in the area. A fourth set of narrow, sinuous anomalies is related to flows that filled ancient valleys during the late stage of Yakima volcanism. The magnetic map suggests that the Ice Harbor dikes are truncated by the Rattlesnake-Wallula fault and related faults, which form a segment of the Olympic-Wallowa lineament. The aeromagnetic map is of great help in delineating the extent of the dikes, mapping the ancient drainage system, and understanding the structural history of this part of the Columbia Plateau.

INTRODUCTION

In 1957, a detailed total-intensity aeromagnetic survey with a fluxgate magnetometer was made of a 27,000-km² area in south-central Washington and north-central Oregon (fig. 1). This area is in the west-central part of the Columbia Plateau, a large physiographic and geologic province underlain by the Columbia River Basalt Group, primarily the Yakima Basalt, and younger sedimentary rocks. The Yakima Basalt is poorly exposed throughout much of the area, and the aeromagnetic data aid in locating and interpreting hidden structures, dikes, and ancient valleys filled with thick Yakima flows.

The aeromagnetic map was compiled by J. R. Kirby and D. L. Daniels in 1970 from profiles oriented along north-south flights spaced about 1.6 km apart and 150 m above ground. The regional gradient was removed (Fabiano and Peddie, 1969), and the data contoured in intervals of 20 gammas. This map is generally consistent with but much more detailed than the high-altitude (4,600 m) aeromagnetic map of part of the same area (Zietz and others, 1971); specific examples of this consistency are described below.

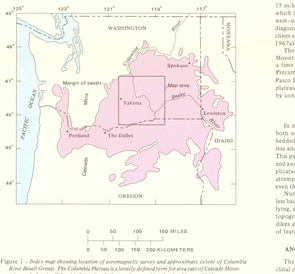


Figure 1 — *Index map showing location of aeromagnetic survey and approximate extent of Columbia River Basalt Group. The Columbia Plateau is a loosely defined term for area east of Cascade Mountains underlain by Columbia River Basalt Group. Extent of basalt after Waters (1961).*

We have interpreted the aeromagnetic data on the basis of reconnaissance fieldwork by Swanson and Wright, supplemented by published geologic maps, especially those of Grolier and Bingham (1971) and Swanson and others (1977). Detailed geologic maps are not available for much of the surveyed area, and some of the existing maps are inadequate because they predate recent advances in knowledge of the basalt stratigraphy. Consequently we cannot make a geologic evaluation of each aeromagnetic anomaly, although most of the major anomalies can be related to known or reasonably inferred geologic features. The tectonic map of Newcomb (1970), part of which is shown in modified form in figure 2, is the most complete structural compilation available and shows the general distribution of the basalt and younger sedimentary rocks. No modeling of anomalies was attempted, owing to the paucity of information on magnetic properties such as susceptibility and Q-values. We hope that this aeromagnetic map and our preliminary interpretation of it will encourage further study of the relation between geology and rock magnetism on the Columbia Plateau.

GEOLOGIC SETTING

The bedrock in the map area is the Yakima Basalt, the youngest formation in the Columbia River Basalt Group. The Yakima is a sequence of flood basalt flows mostly erupted during a 3-m.y. period about 15 m.y. ago (Watkins and Baksi, 1974), although eruptions continued intermittently until about 6 m.y. ago (McKee and others, 1977). The basalt has been subdivided into several units, summarized in figure 3. The maximum thickness of Yakima Basalt in this area is at least 600 m (Davy and McKee, 1969) and may be several times that. An oil-test hole on the Rattlesnake Hills about 60 km west-northwest of Pasco penetrated 3,248 m of basalt and andesite(?) without cutting basement (Raymond and Tillson, 1968), but at least the lower 1,800 m of the basalt and andesite(?) may be pre-middle Miocene (Newman, 1970) and therefore older than the Yakima Basalt. The basalt was presumably erupted from north-northwest-trending fissures, those for the Ice Harbor flows (Swanson, Wright, and Helz, 1975; fig. 3) being located in the southeast corner of the map area.

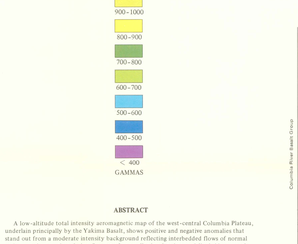


Figure 2 — *Simplified geologic map superimposed on reduced aeromagnetic map of west-central Columbia Plateau. Structures simplified and slightly modified from Newcomb (1970), with additions near Wallula Gap from Bingham, Londquist, and Baltz (1970), Swanson and others (1977) and Swanson and Wright (unpub. data, 1976). The most important structures have topographic expression, as shown by comparison with topographic map to aeromagnetic map.*

ANOMALIES RELATED TO STRUCTURALLY CONTROLLED TOPOGRAPHY

The Yakima Basalt is uplifted and folded along several long narrow anticlinal and monoclinal ridges in the area (Waters, 1955; Newcomb, 1970). Many of the anticlines are asymmetric, generally with a steeper north limb forming an abrupt scarp. The aeromagnetic anomalies reflect these anticlinal ridges and their asymmetry. Examples are the Horse Heaven Hills between long 119° and 120°W. (anomalies 1 and 1A on map), the Rattlesnake Hills-Red Mountain–Badger Mountain chain of ridges west of Pasco (2), Toppenish Ridge (3), Yakima Ridge (4), parts of Gable Mountain and Gable Butte on the Hanford Reservation (5), Saddle Mountains (6), to a poor degree the Frenchman Hills (7), and the Alder Ridge–Golgotha Butte area northeast of Arlington, Oreg. (8). These anomalies are presumably related to flows that dip away from the eroded ridgecrest; as a result of the dip and the erosion, flow sequences of uniform magnetic polarity are exposed rather than hidden in the "sandwich" of normal and reversed flows that characterizes areas between ridges. Anomaly 2 may additionally reflect faulting along the Rattlesnake – Wallula fault (Bingham and others, 1970) as well as topography, a possibility discussed in a later section.

The anomalies are paired along some of the steepest north-facing scarps, a positive anomaly occurring near the top of the scarp and a negative anomaly toward the base; good examples are anomalies 1 and 2. This may largely result from the fact that the Earth's magnetic field is not vertical in this area (Nettleton, 1971). Changing flight-altitude may contribute significantly to the anomaly pattern, although a nearly constant altitude above ground was supposedly maintained.

Another type of topography-related anomaly is the sinuous magnetic high (9) that approximately coincides with the north bank of the Columbia River upstream from McNary Dam, 30 km southwest of Pasco. Here, bold cliffs exposing nearly horizontal flows of normally polarized basalt, chiefly the Frenchman Springs Member, were produced during the late Pleistocene floods that drained Lake Missoula (Bretz and others, 1956; Baker, 1973) and stripped away unconsolidated sedimentary deposits overlying the basalt. The positive magnetic anomaly may reflect these bare cliffs.

Anomalies 29–32 are negative and follow steep canyons of the Snake and Columbia Rivers. Presumably these anomalies are artifacts caused by the difficulty in maintaining the same flight altitude above ground as the canyons were crossed.

ANOMALIES RELATED TO DIKES

The cluster of four positive and negative anomalies (10–13) trending N.20°-30°W. in the southeast part of the area crosses nearly flat, featureless terrain. Single anomalies within this cluster are as much as 80 km long, less than 4 km (generally less than 2 km) wide, and have amplitudes of 400–500 gammas relative to the regional background. The anomalies are remarkably straight, continuous, and symmetric and show no change in character as they pass from areas of basalt outcrop into areas where the basalt is covered by thin sedimentary deposits. The anomalies are probably shallow features, as suggested by their high gradient, narrow width, and absence from the high-altitude aeromagnetic map (Zietz and others, 1971, fig. 1).

We interpret these anomalies to be caused by a system of mostly concealed dikes known from geologic mapping to occur in the area (Swanson and others, 1972; Swanson, Wright, and Helz, 1975; Swanson and others, 1977). These dikes fed the Ice Harbor flows, which are 8.5 m.y. old (McKee and others, 1977) and constitute the youngest flows of the Yakima Basalt within the area of the aeromagnetic map. The Ice Harbor flows have been subdivided (Helz and others, 1976; Swanson, Wright, and Helz, 1975) into four subunits, from oldest to youngest with paleomagnetic polarity in parentheses, Basin City (normal), Ice Harbor 1 (reversed), upper Ice Harbor 1 (reversed), and Ice Harbor 2 (normal). The paleomagnetic polarities were determined in the field with a portable fluxgate magnetometer, and later in the laboratory using oriented cores (written commun., S.R. Choiniere, May 1976).

Swanson, Wright, and Helz (1975) described 18 vent and near-vent areas for these four units and showed how they were aligned into linear vent systems along the aeromagnetic anomalies. Additional dikes for Ice Harbor 2 occur about 2 km west of Reese (T. 7 N., R. 32 E.) (Swanson and others, 1977). The northern third of the Basin City vent system follows a narrow, shallow graben (Swanson, Wright, and Helz, 1975, p. 894). The Ice Harbor 1 vent system occurs along the western negative anomaly (11), the upper Ice Harbor 1 system along the eastern negative anomaly (13), and the Basin City and Ice Harbor 2 systems along the intervening positive anomaly (12). Two vent areas for Ice Harbor 2 deviate from the general pattern and suggest a right-offset en echelon fissure set not reflected by the magnetic pattern (Swanson, Wright, and Helz, 1975, p. 894-895). No dikes have been found for the broad westernmost positive anomaly (10), but this area is completely covered with young sedimentary deposits. In fact, the entire area underlain by the Ice Harbor flows is poorly exposed, and the aeromagnetic data provide a far more complete picture of the extent of the dike swarm than does the field mapping alone.

The observed dikes are all nearly vertical and thin (less than 3 m wide) and trend parallel to the anomalies. It seems unlikely, however, that one such dike could itself be responsible for the size and amplitude of a particular anomaly. More likely a set of several closely spaced dikes of uniform polarity or a single wide dikelike body underlies each anomaly. For example, two dikes and one thin dikelet occur on the north bank of the Snake River where it crosses anomaly 12.

The anomalies do not strictly parallel each other but instead trend more northerly in the west than in the east. Such a difference in azimuth could be related to slight tectonic rotation, if it could be demonstrated that the ages of the dikes change systematically across the swarm. This is not the case, however, as the oldest dikes (Basin City) are sandwiched between younger dikes. Apparently the divergent trends are related to something other than rotation.

Axes of small warps in the basalt, with amplitudes of less than 10-20 m, locally are subparallel to the magnetic anomalies (fig. 2; Swanson and Wright, unpub. data, 1978). These structures may affect the magnetic signature somewhat. However, the warps neither coincide with nor extend as far as the anomalies; this is especially apparent in the well-exposed areas of nearly flat-lying basalt along the Snake River and northwest of Eltopia. Thus we feel that the structures as seen on the surface are not the prime cause of the anomalies. If the structures are more extensive at depth, they could contribute significantly to the linear magnetic pattern, but positive evidence for this is lacking. The structures may be related to the intrusion of the dikes in the area.

Several other narrow northwest-trending anomalies may be related to dikes, although no dikes have been found associated with them. Examples are the negative anomalies (14) that cross the Snake River near the border of T. 10 and 11 N., R. 33 E., near the railroad siding called Snake River; the anomalies (15) in and adjacent to T. 15 and 16 N., R. 31 E. west of Cunningham; and the general northwest grain (16) in T. 14 and 15 N., R. 33 E. southeast of Cunningham. These anomalies all have lower amplitudes than those of the Ice Harbor dike swarm and may reflect smaller or more deeply buried dike systems.

One thick and two thin dikes, feeders for a normally polarized, highly plagioclase-phyric flow in the Frenchman Springs Member, are located on both sides of the Snake River in sec. 1, T. 11 N., R. 33 E., 10 km northeast of the railroad siding Snake River (Swanson, Wright, and Helz, 1975, pl. 1B). These dikes, which trend N. 25° W., have little magnetic expression, suggesting that they do not greatly widen or become more numerous within the depth range affecting the magnetometer.

ANOMALIES RELATED TO FAULTS

The anomalies related to the Ice Harbor dikes terminate south of the Walla Walla River against a zone of west-northwest-trending positive and negative anomalies that form the southeast continuation of the Rattlesnake Hills-Red Mountain-Badger Mountain trend. No Ice Harbor dikes have been found during mapping south of this trend (Swanson and Wright, unpub. data, 1978). The axis of one of the west-northwest-trending negative anomalies (17) occurs along a fault mapped by Newcomb (1965) that defines the southwest margin of the Walla Walla Basin. Farther northwest, this anomaly corresponds with the Rattlesnake-Wallula fault of Bingham, Londquist, and Baltz (1970), exposed northwest and east of Wallula Gap (for example, at 17A). Swanson and Wright (unpub. data, 1976) and Gardner (1977) found fault breccia and offset stratigraphy along the trace of the aeromagnetic anomaly east-southeast and north of Wallula Gap, confirming the observations of Bingham, Londquist, and Baltz (1970). This anomaly, which extends at least as far northwest as the Rattlesnake Hills, may partly reflect the topography along the eastern extension of the Horse Heaven Hills anticline (2), but basic fault control is suggested by the relation of the anomaly to the Ice Harbor anomalies and to the recognized faults. The reversely magnetized Pomona Basalt Member and flows of Ice Harbor 1 type form cuestas and hogbacks in many places along the fault. Dips very from 5° to 40° or more toward the northeast. These dipping flows, generally associated with fault breccia, may account for the linear negative anomalies.

Other anomalies east of Wallula Gap follow the linear valleys of Vansycle Canyon, Warm Springs Canyon, and the valley east of Warm Springs Canyon, mapped as faults or fracture zones by Newcomb (1965), Bingham, Londquist, and Baltz (1970), and Walker (1973). The west-northwest-trending Wallula Gap fault (Bingham and others, 1970; Swanson and others, 1977), well exposed on the northwest side of Wallula Gap, is coincident with a steep magnetic gradient between a west-northwest-trending high on the north side and a parallel low on the south side. The Wallula Gap fault apparently joins the Rattlesnake-Wallula fault several kilometers east of Wallula Gap. Bingham, Londquist, and Baltz (1970) mapped another fault, the Badger Coulee fault, about 30 km west-northwest and along the approximate strike of the Wallula Gap fault; the aeromagnetic map shows no strong trend along the trace of the Badger Coulee fault or its projection, although the west-northwest magnetic grain is apparent. In summary, both geologic and aeromagnetic evidence supports the existence of a complex fault zone in the area of truncated dike-related anomalies.

Most of the faults recognized in the field have a similar sense of displacement, northeast side down. These faults are probably normal, as indicated by vertical to steeply northeast-dipping zones of fault breccia at several places along the Rattlesnake-Wallula and Wallula Gap faults and at two localities in Vansycle Canyon. The maximum displacement is difficult to estimate but is more than 50 m near Wallula Gap.

The Rattlesnake-Wallula fault and associated faults form part of the Olympic-Wallowa lineament, as defined by Raisz (1945) on the basis of topography and discussed by many workers, especially Wise (1963), Skehan (1965), Watkins (1965, 1967), and Taubeneck (1966, 1967). Whether this topographic lineament has regional tectonic significance is debatable, but available evidence now favors the Rattlesnake Hills-Wallula Gap segment of the lineament being at least partly fault controlled.

Other anomalies on the map may be associated with faults and shear zones. For example, the strong west-northwest grain in the extreme southwest part of the map area has the same trend as faults that occur a few kilometers farther west and south (Newcomb, 1970, fig. 2) and may reflect similar structures. These anomalies cross shallow east-trending folds of the Yakima Basalt in the Columbia River gorge, but the folds are not associated with the Horse Heaven Hills in T. 6 N., R. 19 E., 18 km east-northeast of Satus Pass. An alternative explanation for the anomalies is that they reflect a hidden dike swarm. We do not favor this origin, because elsewhere on the Columbia Plateau all observed dikes trend north to north-northwest. The Ice Harbor dikes (anomalies 10–13) exemplify this orientation.

ANOMALIES ASSOCIATED WITH VALLEY – FILLING BASALT FLOWS

Ancient valleys filled with basalt flows occur on the Columbia Plateau (Lupher and Warren, 1942). These valleys were cut and filled during the waning stage of Yakima volcanism (Swanson, Wright, and Clem, 1975). All known paleovalleys within the map area are reflected by magnetic anomalies; this relation can be used to infer the course of these valleys beneath concealed areas. The anomalies are thought to reflect the filling of narrow valleys by a flow so thick that its magnetic intensity is much stronger than that of wallrock, which consists of interbedded flows of reversed and normal polarity that tend to cancel each other out.

The two narrow, sinuous anomalies (18 and 19) trending east–west between Esquatzel Coulee and the Snake River are in a very poorly exposed area between localities of mapped intracanyon flows. Remnants of intracanyon flows belonging to the Pomona and Elephant Mountain Basalt Members of Schmincke (1967b) occur wherever exposures can be found along these anomalies, such as in Old Maid and Esquatzel Coulees. The Pomona is the only intracanyon flow known to occur along the southernmost (18) of the two anomalies, and its reversed polarity (Rietman, 1966; S. R. Choiniere, written commun., May 1976) probably accounts for the negative anomaly. A flow of the Elephant Mountain Basalt Member is the only known intracanyon flow along the northernmost anomaly (19). A particularly good exposure of an Elephant Mountain flow filling a valley in at Cactus Siding in Esquatzel Coulee (Grolier, 1965, p. 107–108). The intracanyon Elephant Mountain flow has a normal polarity, as determined by S. R. Choiniere (written commun., May 1976) using laboratory techniques, consistent with the positive nature of the anomaly.

The two anomalies converge eastward and appear to connect with mapped remnants of valley-filling Pomona and Elephant Mountain flows in Wilson Canyon, 3 km west of Devils Canyon. These and other valley-filling flows can be traced in the field eastward from Wilson Canyon for many tens of kilometers; they define the location of the ancestral Snake River during late Miocene time. Were it not for the aeromagnetic data, we would be unable to trace the ancient valleys between Esquatzel Coulee and Wilson Canyon, and thus these data are of much importance in determining the late Miocene paleogeography of the area.

Using this example as a guide, we suggest that several other narrow, sinuous anomalies on the map reflect ancient lava-filled valleys. One such example about 5 km west and northwest of Othello is especially clear. Here an unnamed flow, recognized as occurring in a narrow valley no more than 300 m wide by Grolier (1965, p. 106–107) and mapped by Grolier and Bingham (1971), coincides with a gently curving, narrow, southwest-trending positive magnetic anomaly (20). The magnetic polarity of the flow, as determined in the field with a portable fluxgate magnetometer, is also normal. This anomaly can be traced with confidence northeastward to a point about 8 km southwest of Warden, where it apparently swings eastward (20A) and may continue south of Lind Coulee for 13 km; the mapped intravalley flow also swings eastward with the anomaly, before disappearing beneath younger sedimentary deposits (Grolier and Bingham, 1971). Southwest of the Othello area the anomaly may continue across the Saddle Mountains as far as the Columbia River (20B) and extend up the Columbia at least as far west as long 119°45' W. If Eastern Washington State College Press, Cheney, Wash., p. 201-272.
these anomalies are correct, the aeromagnetic data trace the ancient valley and its basalt fill Raitz, Erwin, 1945, The Olympic-Wallowa lineament: Am. Jour. Sci., v. 243A, p. 479-485.
filling for a distance of 80 km, along most of which no outcrops occur because of younger deposits.

A faint, east–trending negative anomaly (21) about 3 km northeast of Beverly, a village on the Columbia River just north of Saddle Mountains, may correspond to the Ferncliff flow tongue of Grolier (1965, p. 108), which he interpreted to be a valley-filling flow. The narrow, east-trending positive anomaly (22) extending from the westernmost dike(?) anomaly toward Richland may indicate a valley filled with a flow erupted from the dike.

Numerous other narrow, sinuous magnetic anomalies on the map are not associated with obvious topography or structure and should be considered as possible indications of old valleys filled with younger basalt flows.

MAJOR ANOMALIES OF UNKNOWN ORIGIN

Several large anomalies have no obvious cause. The most striking is the broad positive anomaly (23) in the area immediately southeast of Cunningham. This anomaly also shows up on the high-altitude magnetic map (Zietz and others, 1971, fig. 1). The basalt in this area is poorly exposed, being mantled except in some valleys by tuffaceous sedimentary deposits and loess (Grolier and Bingham, 1971). A generalized water-level contour map of this area (Lazier and Burt, 1974, pl. 2) shows an area of unusually shallow depth to static water levels in wells updip (northeast) from the area of the magnetic anomaly. This suggests that the anomaly may reflect a structure or rock body that serves as a groundwater barrier. Three possible sources of the anomaly consistent with its appearance on both magnetic maps are a buried mafic intrusive body, a basement high, or a structural dome. Interestingly, the largest ground-water barrier that Lazier and Burt (1974, p. 11–14) found, between Ruff and Lind in the northeast part of the map area, has no strong magnetic expression, although the general magnetic trend in this area parallels the northwest-trending barrier.

Another unexplained feature is the broad positive anomaly (24) south of Richland. This could result from a thick Ice Harbor flow ponded against the ancestral Rattlesnake-Wallula structure. Alternatively, the anomaly could reflect a deeper feature, such as a buried basement high, particularly since the high-altitude aeromagnetic map (Zietz and others, 1971, fig. 1) shows a broad positive anomaly that includes the Richland area.

A nearly circular positive anomaly (25) along the northeast margin of Kittitas Valley north of Ellensburg is also puzzling. The anomaly is centered over alluvium and disrupts a linear, northwest-trending, negative anomaly approximately coincident with a narrow graben thought to offset basalt beneath valley fill (Swanson and G.R. Byerly, unpub. data, 1978). This suggests that the positive anomaly is caused by a post-Yakima feature, possibly a shallow mafic intrusion.

Three broad negative anomalies are of unknown origin. Anomaly 26, in the Quincy Basin north of the Frenchman Hills, is developed over Quaternary fluvial and lacustrine sand and silt (Grolier and Bingham, 1971) and may reflect a thick deposit of these weakly magnetized materials. Anomaly 27, west of Jackass Mountain north of Richland, may have a similar origin, as this area is also underlain by lacustrine clay, silt, and fine sand of Quaternary age (Grolier and Bingham, 1971). Anomaly 28, a lobate anomaly on the Royal Slope and in the western part of the Drumheller Channels, is developed over both basalt flows and Quaternary sedimentary deposits (Grolier and Bingham, 1971) and may have a composite origin. Many of the exposed flows in this area are reversely polarized (Pliest Rapids Member, Pomona Basalt Member of Schmincke, 1967b) and would contribute to a negative anomaly, together with the sedimentary deposits. However, it is also possible that deeper-seated structures are the source of these three anomalies, as the high-altitude aeromagnetic map (Zietz and others, 1971) shows magnetic lows coinciding with anomalies 27 and 28 and the southern part of anomaly 26.

There is one intriguing difference between the high-altitude and low-altitude magnetic maps. The high-altitude map (Zietz and others, 1971, fig. 1) shows a striking linear set of anomalies trending northwest along or somewhat south of the east half of the Horse Heaven Hills anticline (1). This set of high-altitude anomalies extends at least 20 km farther northwest than the low-altitude anomaly and may reflect a deeper part of the structure than can be seen using the low-altitude data.

RELATION BETWEEN AEROMAGNETIC AND GRAVITY ANOMALIES

Correspondence between aeromagnetic and Bouguer gravity (Bonini and others, 1974; Kosticˇek, 1974) anomalies is poor in south-central Washington (fig. 4). The gravity data are most likely influenced by deeper structures and rock bodies than are the low-altitude aeromagnetic data. One possible exception is the spatial correspondence between the aeromagnetic anomaly along the Rattlesnake Hills west of Pasco (2) and a northwest-trending gravity gradient that defines the northeast side of a positive anomaly centered near lat 46° 15' N., long 119°40' W. (fig. 2). Perhaps the aeromagnetic anomaly and gravity gradient are both related to a structure along the Olympic-Wallowa lineament. South of Pasco, however, the aeromagnetic and gravity trends in the area of the lineament are markedly discordant.

Figure 4 — *Complete Bouguer gravity anomaly map (Bonini and others, 1974) superimposed on aeromagnetic map of west-central Columbia Plateau. Note discordant trends of gravity and aeromagnetic data.*

CONCLUSIONS

The low-altitude aeromagnetic map corresponds closely to the known geology and enables extrapolations to be made across poorly exposed areas. It outlines the limits of the Ice Harbor dike system better than would ever be possible from knowledge of the surface geology alone. The anomaly patterns suggest the first evidence of truncation of features along the Rattlesnake-Wallula fault zone. The magnetic map also greatly aids in reconstructing the drainage system that formed during the late stage of Yakima volcanism. The map contributes significantly to an understanding of the late Cenozoic history of the area and suggests areas that should be examined more closely in the field. Aeromagnetic coverage of the entire Columbia Plateau, especially along the southeast extension of the Rattlesnake-Wallula fault, would be invaluable toward this end. Coverage for much of the area will be available in 1978.

ACKNOWLEDGMENTS

We thank J. R. Kirby and D. L. Daniels for compiling the aeromagnetic data; R. T. Helz for considerable help in studying the Ice Harbor dikes; and B. A. Sims for pointing out the paper by Lazier and Burt (1974).

REFERENCES CITED

Baker, V. R., 1973, Paleohydrology and sedimentology of Lake Missoula flooding in eastern Washington: Geol. Soc. America Spec. Paper 144, 79 p.
Bingham, J. W., Londquist, C. J., and Baltz, E. H., 1970, Geologic investigation of faulting in the Hanford region, Washington: U.S. Geol. Survey Open-file report, 104 p.
Bonini, W. E., Hughes, R. W., and Hunsel, Z. F., 1974, Complete Bouguer gravity anomaly map of Washington: Washington Div. Geol. Map GM-11, scale 1:500,000.
Bretz, J. H., Smith, H. T. U., and Neff, G. E., 1956, Channeled scabland of Washington: New data and interpretations: Geol. Soc. America Bull., v. 67, p. 957-1049.
Brown, D. J., and Ledgerwood, R. K., 1973, Stratigraphy and structure of Yakima Basalt in the Pasco Basin, Washington: Oregon Dept. Geology and Mineral Industries Bull. 77, p. 171-181.
Davy, H. D., and McKee, Bates, 1969, Stratigraphy of the Yakima Basalt in the type area: Northwest Sci., v. 143, p. 47-64.
Fabiano, E. B., and Peddie, N. W., 1969, Grid values of total magnetic intensity IGRF-1965: ESSA Tech. Rept. C & GS 38, 55 p.
Gardner, J. N., 1977, Stratigraphy and faulting of Columbia River basalt in Wallula Gap, Washington: Am. Geophys. Union, Trans. (EOS), v. 58, no. 12, p. 1247-1248.
Grolier, M. J., 1965, Geology of part of the Big Bend area in the Columbia Plateau, Washington: Johns Hopkins University, Baltimore, Md., Ph. D. thesis, 267 p.
Grolier, M. J., and Bingham, J. W., 1971, Geologic map and sections of parts of Grant, Adams, and Franklin Counties, Washington: U.S. Geol. Survey Misc. Geol. Inv. Map I-589, scale 1:62,500.
Helz, R. T., Wright, T. L., and Swanson, D. A., 1976, Petrogenetic significance of chemical trends in the youngest unit of Yakima Basalt on the Columbia Plateau, northwest U.S.A., *in* Gonzalez-Ferran, O., ed., Proceedings Andean Antarctic Volcanology Symposium: Inter. Assoc. Volcanol. Chem. Earth's Interior Special Series, p. 465-481.
Hill, D. P., 1972, Crustal and upper mantle structure of the Columbia Plateau from long range seismic-refraction measurements: Geol. Soc. America Bull. v. 83, p. 1639-1648.
Holmgren, D. A., 1970, K/Ar dates and paleomagnetics of the type Yakima Basalt, central Washington, *in* Gilmour, E. H., and Strudling, Dale, eds., Proceedings of the Second Columbia River Basalt Symposium: Eastern Washington State Coll. Press, Cheney, Wash., p. 189-199.
Karig, D. E., 1971, Origin and development of marginal basins in the western Pacific: Jour. Geophys. Research, v. 76, p. 2542-2561.
Kosticˇek , D. L., 1974, Geophysical survey in south-central Washington: Univ. of Puget Sound, Tacoma, Wash., M.S. thesis, 35 p.
Lupher, R. L., and Warren, W. C., 1942, The Ascotin stage of the Snake River Canyon near Lewiston, Idaho: Jour. Geology, v. 50, p. 664-681.
Luzier, J. E., and Burt, R. J., 1974, Hydrology of basalt aquifers and depletion of ground water in east-central Washington: Wash. State Dept. Ecology Water-Supply Bull. 33, 53 p.
McKee, E.H., Swanson, D. A., and Wright, T.L., 1977, Duration and volume of Columbia River basalt volcanism, Washington, Oregon, and Idaho: Geol. Society America Abs. with Programs, v. 9, no. 4, p. 463-464.
Nettleton, L. L., 1971, Elementary gravity and magnetics for geologists and seismologists: Soc. Exploration Geophys., Mon. 1, 121 p.
Newcomb, R. C., 1965, Geology and ground-water resources of the Walla Walla River Basin, Washington-Oregon: Washington Div. Water Res., Water Supply Bull. 21, 151 p.
——1970, Tectonic features of the main part of the basalt of the Columbia River Group, Washington, Oregon, and Idaho: U.S. Geol. Survey Misc. Geol. Inv. Map I-587, scale 1:500,000.
Newman, K. R., 1970, Palynology of interflow sediments from the Standard Oil Company of California Rattlesnake Hills No.1 well, Benton County, Washington, *in* Gilmour, E. H., and Strudling, Dale, eds., Proceedings Second Columbia River Basalt Symposium: Eastern Washington State College Press, Cheney, Wash., p. 201-272.
Raitz, Erwin, 1945, The Olympic-Wallowa lineament: Am. Jour. Sci., v. 243A, p. 479-485.
Raymond, J. R., and Tillson, D. D., 1968, Evaluation of a thick basalt sequence in south-central Washington: U.S. Atomic Energy Commission Research and Development Report BNWL-778, 128 p.
Rietman, Jan, 1966, Remanent magnetization of the late Yakima Basalt, Washington State: Stanford Univ., Stanford, Calif., Ph. D. thesis, 87 p.
Schmincke, H-U., 1967a, Flow directions in Columbia River basalt flows and paleocurrents of interbedded sedimentary rocks, south-central Washington: Geol. Society America, v. 56, p. 992-1020.
——1967b, Stratigraphy and petrography of four upper Yakima basalt flows in south-central Washington: Geol. Soc. America Bull., v. 78, p. 1385-1422.
Skehan, J. W., 1965, A continental-oceanic crustal boundary in the Pacific Northwest: Air Force Cambridge Research Lab., Scientific Rept. 3, AFCRL-65-904, 52 p.
Swanson, D. A., and Wright, T. L., 1976, Magnetostratigraphic units in the Yakima Basalt, southeast Washington: Geol. Soc. America Abs. with Programs, v. 8. no. 3, p. 413-414.
Swanson, D. A., Wright, T.L., Camp, V.E., Gardner, J.N., Helz, R.T., Price, S.A., and Ross, M.E., 1977, Reconnaissance geologic map of the Columbia River Basalt Group, Pullman and Walla Walla quadrangles, Washington and adjacent Idaho: U.S. Geol. Survey open-file report 77-100, scale 1:250,000.
Swanson, D. A., Wright, T. L., and Clem, Richard, 1975, Intracanyon flows of Yakima Basalt along the Snake River, southeast Washington: Geol. Soc. America Abs. with Programs, v. 7, no. 5, p. 645.
Swanson, D. A., Wright, T. L., and Helz, R. T., 1975, Linear vent systems and estimated rates of magma production and eruption for the Yakima Basalt on the Columbia Plateau: Am. Jour. Sci., v. 275, p. 877-905.
Swanson, D. A., Wright, T. L., Grolier, M. J., Higgins, M. W., and Zietz, Isidore, 1972, Feeder dikes for Yakima Basalt near Pasco, Washington: Geol. Soc. America Abs. with Programs, v. 4, no. 3, p. 245.
Taubeneck, W. H., 1966, An evaluation of tectonic rotation in the Pacific Northwest: Jour. Geophys. Research, v. 71, p. 2113-2120.
——1967, Reply: Jour. Geophys. Research, v. 72, p. 1415-1421.
Walker, G. W., 1973, Reconnaissance geologic map of the Pendleton quadrangle, Oregon and Washington: U.S. Geol. Survey Misc. Geol. Inv. Map I-727, scale 1:250,000.
Waters, A. C., 1955, Geomorphology of south-central Washington, illustrated by the Yakima East quadrangle: Geol. Soc. America Bull., v. 66, p. 663-684.
——1961, Stratigraphic and lithologic variations in the Columbia River basalt: Am. Jour. Sci., v. 259, p. 583-611.
Watkins, N. D., 1965, Paleomagnetism of the Columbia plateaus: Jour. Geophys. Research, v. 70, p. 3179-3406.
——1967, Comments on a paper by William H. Taubeneck, "An evaluation of tectonic rotation in the Pacific Northwest": Jour. Geophys. Research, v. 72, p. 1411-1414.
Watkins, N. D., and Baksi, A. K., 1974, Magnetostratigraphy and oroclinal folding of the Columbia River, Steens, and Owyhee basalts in Oregon, Washington, and Idaho: Am. Jour. Sci., v. 274, p. 148-189.
Wise, D. U., 1963, An outrageous hypothesis for the tectonic pattern of the North American Cordillera: Geol. Soc. America Bull., v. 74, p. 357-362.
Wright, T. L., Grolier, M. J., and Swanson, D. A., 1973, Chemical variation related to the stratigraphy of the Columbia River basalt: Geol. Soc. America Bull., v. 84, p. 371-386.
Zietz, Isidore, Hearn, B. C., Higgins, M. W., Robinson, G. D., and Swanson, D. A., 1971, Interpretation of an aeromagnetic strip across the northwestern United States: Geol. Soc. America, v. 82, p. 3347-3372.

For sale by Branch of Distribution, U. S. Geological Survey, Box 25286, Federal Center, Denver, CO 80225