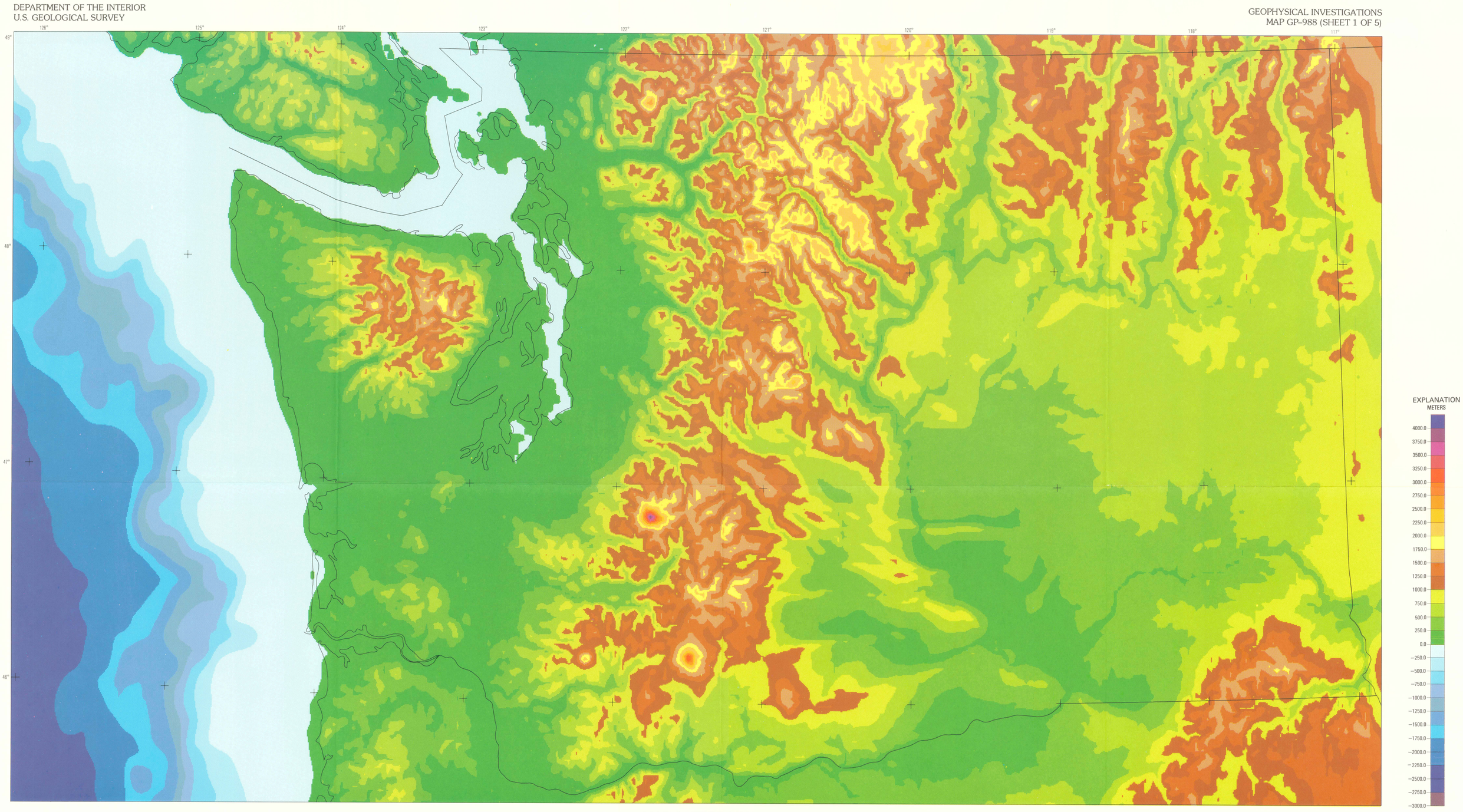
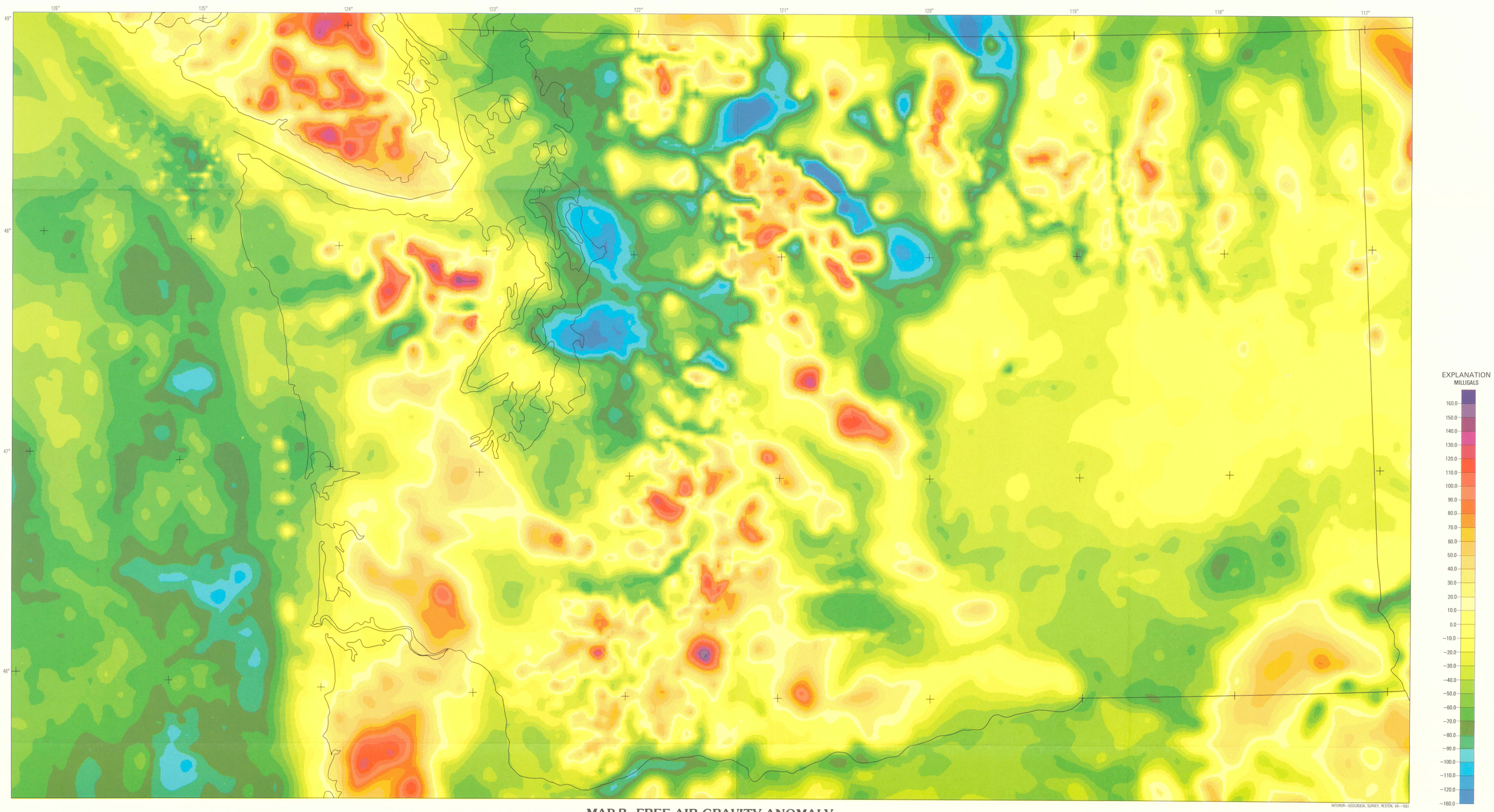



MAP A. TERRAIN




MAP B. FREE-AIR GRAVITY ANOMALY

SCALE 1:1 000 000

25 0 25 50 75 100 MILES

25 0 25 50 75 100 KILOMETERS

## INTRODUCTION

This set of seven maps, showing gravity anomalies and terrain of Washington, displays various qualities of the gravity field in order to aid in their interpretation. Six maps, at a scale of 1:1,000,000, include a terrain map, a free-air anomaly map, a complete-Bouguer anomaly map, two wavelength-filtered maps of the Bouguer anomaly (one of wavelengths greater than 100 km and one of wavelengths less than 100 km), and a map showing the amplitude of the horizontal gradient of the Bouguer anomaly. The seventh map (in four parts) is a version of the complete-Bouguer anomaly map at a scale of 1:500,000, which is the scale of the Washington geologic map (Huntting and others, 1961) and the U.S. Geological Survey Washington state map.

Data from 24,526 gravity stations were used to compile the gravity maps. Sources of the data are the U.S. Defense Mapping Agency; the Earth Physics Branch, Department of Energy, Mines and Resources, Canada; Oregon State University (Couch, Pitts, Braman, and Gemperle, 1980; Couch, Pitts, Veen, and Gemperle, 1980); University of Puget Sound (Danes and Phillips, 1983); Sherrard and Flanigan (1982, 1983); Gerda Abrams (written commun., 1983); Finn and Williams, (1983); and Finn (1984). The data cover an area from lat. 45.5° N. to lat. 49° N. and from long. 117° W. to long. 126° W. All gravity values were adjusted to conform to the International Gravity Standardization Net of 1971 (Morelli and others, 1974). Terrain data are from digital files from the U.S. Defense Mapping Agency and the Earth Physics Branch, Canada.

All seven maps were prepared using the Lambert Conformal conic projection (central meridian of 120.5° W. and standard U.S. parallels of 33° N. and 45° N.). The data were spaced on a 2.0–km grid by means of a computer program (Webring, 1981) that uses a minimum-curvature interpolation formula (Briggs, 1974). The maps were plotted using Applicon, Inc.[1], proprietary color computer software.

The funding for the publication of the maps is from the U.S. Geological Survey State Cooperative Program and from the Division of Mines and Geology, State of Washington.

## GEOGRAPHIC AND GEOLOGIC SETTING

Washington has a wide variety of topographic features (map A). About half of the state consists of the gentle terrain of the Columbia Plateau in the east and the Puget-Willamette Lowlands in the west. The rest of the state consists of the relatively rugged and high terrain of the Cascade Ranges, Coast Ranges, the Olympic Mountains, and the Okanogan Highlands.

Washington has a complex tectonic history. Precambrian sedimentary rocks that crop out at the northwestern part of the state near the Idaho border are thought to delineate the western edge of the Precambrian North American continent (Davis and others, 1978; Hamilton, 1978). Since then, "exotic" blocks have been accreted to the continent, in some places intruded by granitic plutons (in central Washington) and have been generally metamorphosed. During this time arc magmatism related to the subduction of oceanic lithosphere has migrated westward to its present position in the Cascade Range. The Columbia Plateau province of extensive flood basalts is located in the Columbia Embayment, the eastern edges of which are thought to be the Cretaceous coast line (Davis and others, 1978). Faulting has produced grabens in the Okanogan Highlands and northern Cascades, and in some cases has displaced terrain hundreds of kilometers (Hamilton, 1978; Davis and others, 1978).

[1]Use of trade names does not imply endorsement by the U.S. Geological Survey.

## FREE-AIR GRAVITY ANOMALY MAP

In a free-air anomaly map, no correction is made for the Earth's mass between the gravity station and sea level (topography). Local topography causes short-wavelength, free-air anomalies that dominate the free-air gravity anomaly map (map B). Long-wavelength anomalies reveal isostatic compensation. The excess of mass represented by the higher topography is assumed to be isostatically compensated by a corresponding deficiency of mass at depth. If the mass deficiency (compensation) occurs directly beneath the topography, it is called local compensation (Heiskanen and Vening Meinesz, 1958) and for broad features would produce a near-zero free-air anomaly. If the mass deficiency also extends laterally away from (as well as vertically below) the feature, it is called regional compensation and produces positive free-air anomalies over the features, flanked by broader negative anomalies (Cordell, 1979).

## BOUGUER ANOMALY MAP

The Bouguer gravity anomaly maps (map C1–4, four maps at a scale of 1:500,000, and map D at a scale of 1:1,000,000) were prepared using the 1967 gravity formula (International Association of Geodesy, 1967) and a Bouguer reduction density of 2.67 g/cm$^3$. The maps show free-air anomalies offshore. These data were also published at a scale of 1:250,000 (Finn and others, 1984). A Bouguer reduction density of 2.67 g/cm$^3$ is appropriate for the Washington area, because much of the terrain is Paleozoic and Mesozoic oceanic and granitic rocks. Terrain corrections extending radially from 0.895 to 167 km from each gravity station were made by computer (Plouff, 1977). Terrain corrections for the inner zone (0.0–0.895 km) were omitted but are assumed to be less than 2 mgals. However, they may be larger for stations in exceptionally rugged terrain. The omission of these inner terrain corrections may cause the Bouguer gravity anomalies to be more negative than corrected values would be. For a more complete description of the gravity reduction procedure used at the U.S. Geological Survey, see Cordell and others (1982).

Major Bouguer gravity highs (maps C1–4, D) in the study area are associated with the Columbia Plateau, the Coast Ranges, and Vancouver Island. The Columbia Plateau has thick sections of widespread Miocene flood basalts. The gravity high associated with the plateau may be the result of the high density of these basalts as well as to a shallow mantle. The Coast Ranges and Vancouver Island may be island arc or other exotic oceanic terranes that were accreted to the continent in late Mesozoic and early Cenozoic time. Both areas are composed of thick sections of relatively high-density basalt that contribute to the observed Bouguer gravity highs (Finn, 1988).

Bouguer gravity lows are associated with the other major high topographic areas on the map (the Olympic Mountains, the Cascade Range, the Okanogan Highlands, and the Blue Mountains Province). The source of these anomalies is probably local or regional isostatic compensation of the mountains. Two large amplitude oval gravity lows occur in the graben of the Puget Lowland at about long. 122° W. and lat. 48° N. These lows are caused by more than 3,600 ft of unconsolidated sediments (Hall and Othberg, 1974).

Offshore, the major low on the Bouguer map (as well as the free-air map) is the north-south trending linear anomaly west of the Coast Range associated with the negative density contrast between sediments within the Juan de Fuca trench and surrounding marine basalts (Finn, 1988).

## WAVELENGTH-FILTERED MAPS

Wavelength filtering separates long-wavelength anomalies (regional), which are typically associated with deep crustal or subcrustal features, from short-wavelength anomalies (residual), which are associated with shallow features. However, the differentiation of features by depth or wavelength is not always possible; some long-wavelength anomalies can be caused by broad, shallow features. The short-wavelength filter used to produce the residual map (map F) enhances small features, but the anomaly amplitudes are distorted in places by the removal of the long wavelengths (Hildenbrand, 1988).

The Bouguer gravity grid (maps C and D) was used in the wavelength-filtering process. The data were transformed to the frequency domain by the fast Fourier transform (Hildenbrand, 1983) and then were low-pass filtered using a 100-km-wavelength cutoff. This cutoff point is roughly equal to the width of the Cascade Range and is near the 90-km wavelength that Pitts (1979) used in his study of the northern Oregon Cascade Range. The long-wavelength (regional) field (map E) was then calculated by taking the inverse Fourier transform. Map E shows gravity anomalies having wavelengths greater than 100 km. The short-wavelength (residual) field (map F) was calculated by subtracting the long wavelength field from the unfiltered Bouguer gravity field.

The regional map showing wavelengths greater than 100 km (map E) represents the effects of deeper sources such as those providing isostatic compensation of the Cascade Range, shallow mantle, or the ocean-continent crustal transition, and also any broad, shallow masses that may be present.

The residual map (map F) shows local, shallow features. Anomalies on this map may delineate plutons, faults, and low-density basin and caldera fill, or they can result from topographic features where the 2.67 g/cm$^3$ Bouguer reduction density is inappropriate.

## HORIZONTAL GRAVITY-GRADIENT MAP

The magnitude of the horizontal gradient of the gravity field, calculated using a computer program of R. W. Simpson (U.S. Geological Survey, unpub. data), is shown on map G. Maximum gradient magnitudes occur at inflections in the gravity field that, by inference, delineate major, sharp, density boundaries (Cordell, 1979). The maximum gradient occurs exactly over a vertical density boundary; the gradient is slightly shifted where the boundary dips or where a contribution from adjacent sources is significant.

The sharp gradients shown on the western part of the map are partially related to the density contrasts between the surface outcrops of the Coast Range basalts and the surrounding sediments and volcaniclastic rocks. Other causes of the gradients, particularly at Vancouver Island, are due to density differences between oceanic and continental terranes.

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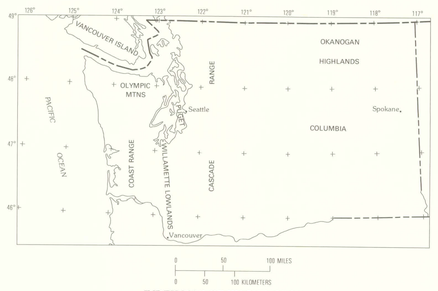


INDEX MAP OF WASHINGTON

# GRAVITY ANOMALY AND TERRAIN MAPS OF WASHINGTON

By
Carol Finn, W. M. Phillips, and D. L. Williams

1991

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