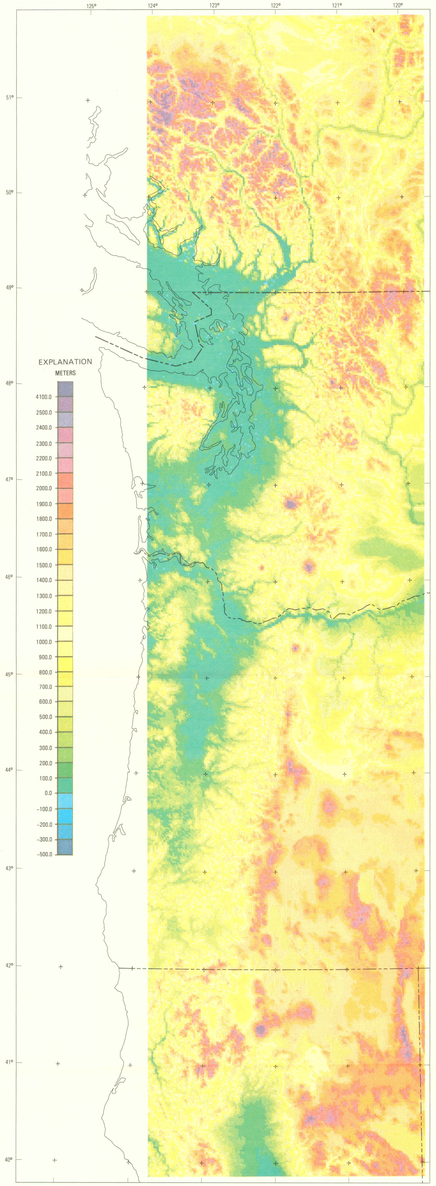
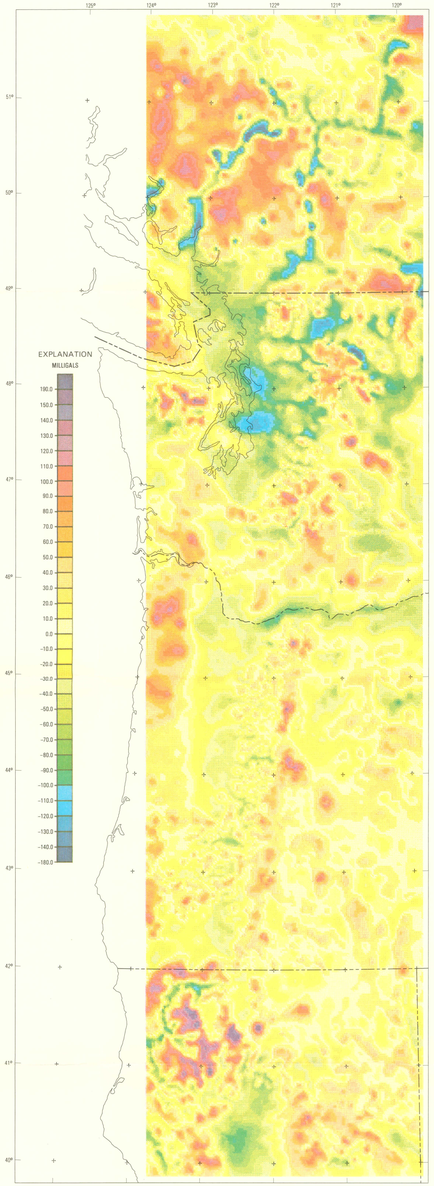
DEPARTMENT OF THE INTERIOR
U.S. GEOLOGICAL SURVEY

GEOPHYSICAL INVESTIGATIONS
MAP GP-972 (SHEET 1 OF 2)

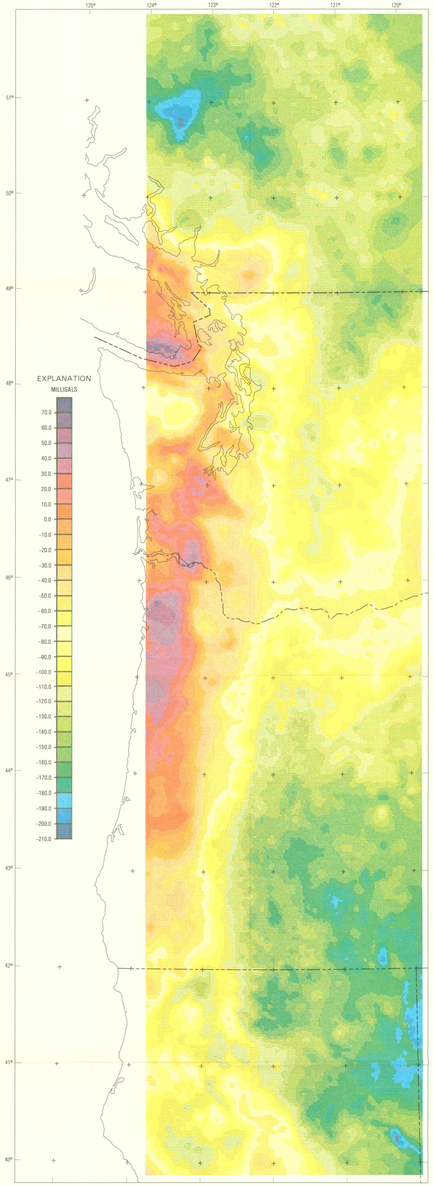


Albers Equal Area projection, central meridian 122°W., standard parallels 29°N and 45.5°N.

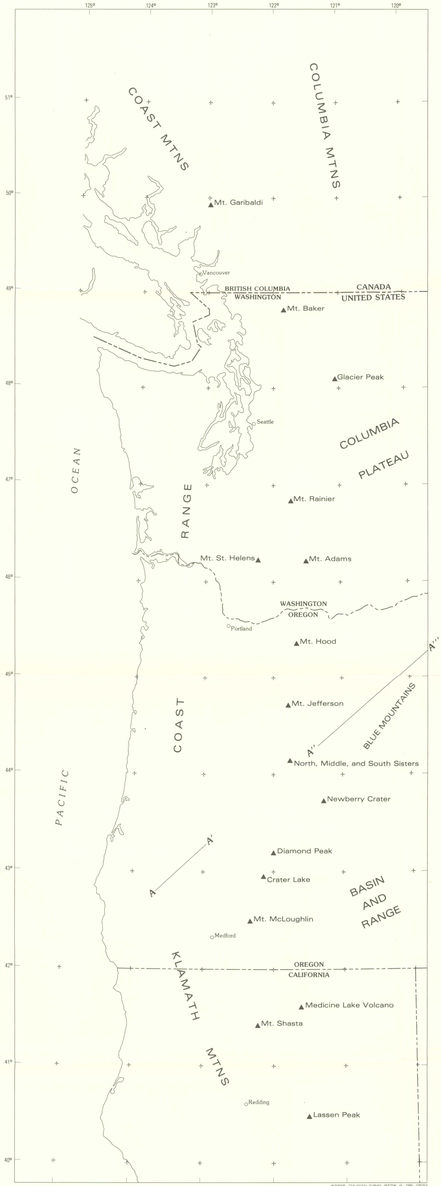
MAP *A*. TERRAIN



MAP *B*. FREE-AIR GRAVITY ANOMALY



MAP *C*. COMPLETE BOUGUER GRAVITY ANOMALY USING REDUCTION DENSITY OF 2.67 GRAMS/CUBIC CENTIMETER



INDEX MAP SHOWING THE CASCADE RANGE

SCALE 1:2 500 000

50 0 50 100 150 200 250 MILES

50 0 50 100 150 200 250 KILOMETERS

GRAVITY ANOMALY AND TERRAIN MAPS OF THE CASCADE RANGE, CALIFORNIA, OREGON, WASHINGTON, AND BRITISH COLUMBIA

By

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1986

INTRODUCTION

This report consists of eight maps showing gravity anomalies in the Cascade Range. The maps are two Bouguer anomaly maps; a free-air anomaly map; a map showing the amplitude of the horizontal gradient of the Bouguer anomaly; wavelength-filtered maps of the Bouguer anomaly, one of wavelengths greater than 100 km and the other of wavelengths less than 100 km; a terrain map produced from the complete terrain data; and a wavelength-filtered terrain map of wavelengths greater than 100 km.

Data from 29,012 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 (Daneš and Phillips, 1983) and the U.S. Geological Survey (Griscom and Roberts, 1982; Sherrard and Flanigan, 1982, 1983; Gerda Abrams, written commun., 1983; Finn, 1981, 1982, 1983; Finn and Spydell, 1982; Finn and Williams, 1983a, b). 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 of the U.S. Defense Mapping Agency and the Earth Physics Branch, Canada.

All eight maps were prepared using the Albers Equal Area projection (central meridian of 122°W. and standard U.S. parallels of 29°N. and 45.5°N.). The data were spaced on a 2.032-km grid by means of a computer program that uses a minimum-curvature interpolation formula (Webring, 1981). The maps were plotted using Applicon Inc.[1] proprietary color computer software.

The gravity studies in the Cascade Range were funded mostly by the U.S. Geological Survey Geothermal Research and Volcano Hazards programs to aid in the assessment of geothermal resources and potential for destructive volcanic eruptions. These maps display various qualities of the gravity data in order to aid in their interpretation.

GEOGRAPHIC AND GEOLOGIC SETTING

The major landscape features of the Pacific Northwest (index map) are shown on the terrain map (map *A*): the Cascade Range (marked by the major volcanic peaks), the Klamath Mountains, the Basin and Range Province, the Oregon and Canadian Coast Ranges, and the Columbia Plateau.

The Cascade Range is a volcanic arc extending from Lassen Peak, Calif. to Mt. Garibaldi, British Columbia, and is related to subduction of the Juan de Fuca, Explorer, and Gorda plates beneath North America. The volcanic arc is about 60 mi wide and ranges in elevation from a few hundred feet to 14,410 feet at the top of Mt. Rainier. The Cascades consist of many rock types ranging in composition from basalt through rhyolite and in age from Miocene to Holocene. The diversity of rock types and basement geology, and the thick volcanic cover cause numerous density contrasts that produce a wide variety of gravity-anomaly patterns.

The study area has a complex tectonic history. The plate-tectonic setting changed from a Precambrian-Devonian passive Atlantic-type margin to an active subduction zone (Dickinson, 1976; Hamilton, 1979; and Hammond, 1979). Also, changes in the direction of subduction and in the location of the subduction zone and its associated magmatic arc have taken place. Various terranes have been accreted and translates have rotated.

FREE-AIR GRAVITY ANOMALY MAP

If the Earth's mass between the gravity station and sea level (the topography) is not corrected for, the effects of local topography produce short-wavelength free-air anomalies that dominate the free-air gravity anomaly map (map *B*). The excess of mass represented by the topography is assumed to be isostatically compensated by a corresponding deficiency of mass at depth. If this deficiency (compensation) occurs directly beneath the topography, it is called local compensation (Heiskanen and Vening Meinesz, 1958), and for very broad features, it produces a very small (near-zero) free-air anomaly. If the mass deficiency 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 and others, 1982).

BOUGUER ANOMALY MAPS

Two Bouguer gravity anomaly maps (maps *C* and *D*) were prepared using the 1967 gravity formula (International Association of Geodesy, 1967) and Bouguer reduction densities of 2.43 g/cm³ and 2.67 g/cm³. Terrain corrections were made by computer (Plouff, 1977) for the region extending radially from 0.895 to 167 km from each gravity station. Terrain corrections for the inner zone (0.0–0.895 km) were omitted but are assumed to be small, 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).

A Bouguer reduction density of 2.67 g/cm³ (map *C*) is probably appropriate for the area north of Mt. Rainier in Washington, because much of the terrain is Paleozoic and Mesozoic oceanic and granitic rocks. The terrain south of Mt. Rainier consists generally of less-dense volcanic rocks, and a lower Bouguer density value may be more appropriate. The gravity anomalies shown on map *C*, associated with the California and Oregon Cascades, are erroneously low because the reduction density of 2.67 g/cm³ is too high; a reduction density of 2.43 g/cm³ (Couch and others, 1982) is more appropriate for that area and was used to compile map *D*.

The major geologic provinces generally have a distinctive gravity character (maps *C*, *D*). The Oregon Coast Range, an accreted island-arc terrane, produces a relative Bouguer gravity high with values averaging about +30 mGals. Another accreted island arc, the Klamath Mountains, produces gravity values averaging about -100 mGals, much lower than those for the Oregon Coast Range (but still a relative gravity high). The Columbia Plateau, a major gravity high, averages about -50 mGals. The gravity low associated with the Cascade Range is not striking on maps *C* and *D* because it is partly masked by the Basin and Range gravity low in the southern part of the range and by the low associated with the Coast Mountains and Columbia Mountains in British Columbia, where gravity values range from -200 mGals to -110 mGals.

WAVELENGTH FILTERED MAPS

The gravity anomaly associated with the Cascade Range is masked by adjacent anomalies. To isolate and enhance this anomaly we filtered the data by means of a computer program using Fourier analysis (Hildenbrand, 1983) and produced maps *E* and *F*.

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

Because the appropriate Bouguer reduction density for most of the Cascade Range is 2.43 g/cm³, we used the Bouguer gravity map reduced at 2.43 g/cm³ (map *C*) in the wavelength-filtering process. The data were transformed to the frequency domain by the fast Fourier transform and then were low-pass filtered (Hildenbrand, 1983) using a 100-km-wavelength cutoff point. This cutoff point is roughly equal to the width of the Cascades and is near the 90-km wavelength that Pitts (1979) used in his study of the central Oregon Cascades. The regional (long-wavelength) field (map *E*) was calculated by taking the inverse Fourier transform after applying the low-pass filter to the Fourier-transformed Bouguer gravity anomaly. Map *E* shows gravity anomalies having wavelengths greater than 100 km. The residual (short-wavelength) field (map *F*) was calculated by subtracting the regional field from the unfiltered Bouguer gravity field reduced at 2.43 g/cm³.

The regional map showing wavelengths greater than 100 km (map *E*) represents the effects of deeper sources such as that providing isostatic compensation of the Cascades or shallow mantle, or the ocean-continent crustal transition, and also any broad, shallow masses that may be present. We also created a regional low-pass wavelength filtered map of the terrain (map *G*) using the 100-km wavelength cutoff point in order to compare it to the wavelength-filtered regional Bouguer gravity map (map *E*). The filtered terrain map looks generally like the inverse of the regional Bouguer gravity map, a result which may indicate that the regional Bouguer gravity map shows mostly isostatic compensation sources. The gravity gradient related to the ocean-continent crustal transition is also seen on the filtered terrain map.

The residual map (map *F*) shows mostly local features. Anomalies on this map may delineate shallow plutons, faults, and low-density basin and caldera fill, or they could be related to an inappropriate Bouguer reduction density.

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 *H*. Maximum gradient magnitudes are at inflection points of the gravity field which, by inference, delineate major sharp density boundaries (Cordell, 1979). The maximum gradient is exactly over a vertical density boundary; the gradient is slightly shifted where the boundary dips or a contribution from adjacent sources is significant.

A strong curvilinear gravity gradient (map *C*, *D*, and *H*) bounds the western edge of the Cascades Bouguer gravity low. This gradient may be caused by as much as 2–4 km of vertical structural offset (Couch and others, 1982; Zucca and others, 1981) and may represent the western edge of the graben in which the Cascades lie (Couch and others, 1982). This strong gradient is superimposed on a broader trend of gravity values that decrease eastward due to thickening of the crust and changes in lithosphere from oceanic in the west to continental in the east (Couch and others, 1982; Lal-ehr, 1965). The sharp gradients bounding the Oregon Coast Range and Vancouver Island are probably due to density differences between oceanic and continental terranes (Riddihough, 1979). Lineament *A*-*A*′, *A*″–*A*‴ (index map, maps *D* and *H*), trending N. 35° E. subparallel to the direction of plate motion of N. 50° E. (Riddihough, 1979), may be related to the density change between oceanic and continental crust (Hyndman, 1979). The lineament bounds pre-Tertiary terrane (the Klamath Mountains on the southwest and the Blue Mountains in the northeast). These terranes may have been connected in the early Tertiary (Hamilton, 1978) and then rotated clockwise westward creating a gap that is now occupied by the California and Oregon Cascade Range. The Klamath Mountains, after rotation with the Blue Mountains, could have moved away from them in a right lateral sense along a strike-slip fault, marked by the lineament, to its present position.

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

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