Isostatic gravity map of the Death Valley ground-water model area, Nevada and California

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INTRODUCTION

Gravity investigations of the Death Valley ground-water model area are part of an interagency effort by the U.S. Geological Survey (USGS) and the Department of Energy (Interagency Agreement DE-AI08-96NV11967) to help characterize the geology and hydrology of southwestern Nevada and parts of California. The Death Valley ground-water model is located between lat 35°00’ and 38°15’N., and long 115° and 118° W.

An isostatic gravity map of the Death Valley ground-water model was prepared from over 40,000 gravity stations, most of which are publicly available on a CD-ROM of gravity data of Nevada (Ponce, 1997). The map also includes gravity data recently collected by the U.S. Geological Survey (Mankinen and others, 1998; Morin and Blakely, 1999). A subset of these gravity data in the Nevada Test Site and vicinity were described in detail by Harris and others (1989) who included information on gravity meters used, dates of collection, sources, descriptions of base stations, plots of data, and digital and paper lists of principal facts. For display purposes only, gravity data within Yucca Flat were thinned by a factor of 10. The digital gravity data set was gridded at an interval of 400 m using a computer program (Webring, 1981) based on a minimum curvature algorithm by Briggs (1974). The resulting grid was then interpolated to a 200-m grid to minimize pixel size, and then it was color contoured.

GRAVITY METHODS

All gravity data were reduced using standard gravity corrections, including: (a) the earth-tide correction, which corrects for tidal effects of the moon and sun; (b) instrument drift correction, which compensates for drift in the instrument's spring; (c) the latitude correction, which incorporates the variation of the Earth's gravity with latitude; (d) the free-air correction, which accounts for the variation in gravity due to elevation relative to sea-level; (e) the Bouguer correction, which corrects for the attraction of material between the station and sea-level; (f) the curvature correction, which corrects the Bouguer correction for the effect of the Earth's curvature; (g) the terrain correction, which removes the effect of topography to a radial distance of 166.7 km; and (h) the isostatic correction, which removes long-wavelength variations in the gravity field inversely related to topography.

Observed gravity values were referenced to the International Gravity Standardization Net 1971 (IGSN 71) gravity datum (Morelli, 1974, p. 18). Free-air gravity anomalies were calculated using the Geodetic Reference System 1967 formula for theoretical gravity on the ellipsoid (International Union of Geodesy and Geophysics, 1971, p. 60) and Swick's formula (1942, p. 65) for the free-air correction. Bouguer, curvature, and terrain corrections were added to the free-air correction to determine the complete Bouguer anomaly at a standard reduction density of 2,670 kg/m^3. Finally, a regional isostatic gravity field was removed from the Bouguer field assuming an Airy-Heiskanen model for isostatic compensation of topographic loads (Jachens and Roberts, 1981) with an assumed crustal thickness of 25 km, a crustal density of 2,670 kg/m^3, and a density contrast across the base of the model of 400 kg/m^3. Gravity values are expressed in milligals (mGal), a unit of acceleration or gravitational force per mass equal to 10^{-5} m/s^2.

Terrain corrections, which account for the variation of topography near a gravity station, were computed using a combination of manual and digital methods. Terrain corrections consist of a three-part process: the innermost or field terrain correction (estimated in the field and typically extending to a radial distance of 53 to 68 m), inner-zone terrain correction, and outer-zone terrain correction.

Inner-zone terrain corrections were made using either Hayford and Bowie (1912) or Hammer (1939) systems that divide the terrain surrounding a gravity station into zones and equal area compartments. Average elevations for each compartment were manually estimated from the largest scale topographic maps available, usually USGS 1:24,000-scale maps. The terrain corrections were then calculated based on the average estimated elevation of each compartment. Inner-zone terrain corrections typically extend to a radial distance of 0.59 to 2.29 km. With the advent of computer processing and the availability of detailed digital elevation models (DEMs), modern day inner-zone terrain corrections were computed using USGS 7.5’ DEMs with a resolution of 30 m derived from USGS 1:24,000-scale topographic maps.

Outer-zone terrain corrections, to a radial distance of 166.7 km, were computed using a DEM derived from USGS 1:250,000-scale topographic maps and an automated procedure (Plouff, 1966; Godson and Plouff, 1988). Digital terrain corrections are calculated by computing the gravity effect of each grid cell using the distance and difference in elevation of each grid cell from the gravity station.

DISCUSSION

In general, isostatic gravity anomalies reflect lateral (horizontal) density variations in the middle to upper crust. Thus, gravity anomalies can be used to infer the subsurface structure of known or unknown geologic features. Gravity anomalies within the Death Valley ground-water model reflect carbonate rocks, calderas, deep sedimentary basins, and linear geologic features such as faults. Many of these features play an important role as aquifers or confining units in the region and their distribution is important to the understanding of the hydrogeologic framework of the area. Pre-Cenozoic carbonate and crystalline rocks underlie most of the region and their subsurface distribution is especially important in evaluating the hydrogeology of the area. Tertiary volcanic rocks also play a significant role in the extensional history of the area and in the formation of large collapse calderas. Thick accumulations of these volcanic rocks are present in the central and northern part of the Death Valley ground-water model (for example, Timber Mountain and vicinity). Quaternary alluvial deposits exist throughout the study area and are composed of non-marine sedimentary and volcanic rocks, generally Oligocene and younger in age. These deposits play an important role in the saturated-zone hydrology of deep alluvial basins within the southwestern Nevada volcanic field (Grauch and others, 1999) and probably in other deep basins as well. Linear isostatic gravity anomalies may reflect faults such as the basin and range bounding Death Valley-Furnace Creek fault on the western margin of the Grapevine

Mountains, in the central and western part of the study area, or the Thirsty Canyon fault zone along the western margin of the Silent Canyon caldera complex at Pahute Mesa (Mankinen and others, 1998), in the central part of the study area.

As expected, gravity highs occur over pre-Cenozoic carbonate and crystalline rocks that typically have densities on the order of 2,700 kg/m^3. Prominent gravity highs occur over the Grapevine Mountains in the central part of the ground-water basin and in the Spring Mountains in the southeast quadrant of the study area. Gravity lows occur throughout the study area and may reflect sedimentary basins filled with low-density alluvial deposits with densities ranging from 1,600 to 2,200 kg/m^3 or thick accumulations of volcanic rocks with densities of about 2,200 to 2,500 kg/m^3. Gravity lows over Owens and Saline Valleys in the western part of the ground-water basin and Las Vegas Valley in the southeast part of the study area reflect thick sediment-filled basins. One of the largest gravity lows in Nevada is associated with a thick volcanic sequence associated with the Silent Canyon caldera complex in the central part of the ground-water basin just north of Timber Mountain.

A number of geophysical studies were undertaken to aid in characterizing the geologic and hydrogeologic setting of the region. A summary of geophysical investigations at Yucca Mountain that includes gravity, magnetics, electrical methods, seismic methods, heat-flow, and stress data was provided by Oliver and others (1995). More recent studies characterized the geophysical framework of the southwestern Nevada volcanic field (Grauch and others, 1999; Mankinen and others, 1999) identifying a number of subsurface features that might control or influence ground-water flow. These features include resurgent calderas and prominent geophysical lineaments that probably reflect faults. Blakely and others (2000) summarized geophysical investigations of the Death Valley regional ground-water basin.

The diverse physical properties of lithologic types that underlie this region are well suited to geophysical investigations. The contrast in density between pre-Cenozoic basement and overlying unconsolidated alluvium, for example, produces a distinctive pattern of gravity anomalies that can be used to predict the depth of pre-Cenozoic basement in three dimensions. In most parts of the study area, this surface corresponds to the top of the carbonate aquifer, an important element of the hydrologic framework. A companion map, which shows the depth to basement, discusses a model of this surface based on the inversion of gravity data (Blakely and Ponce, 2001).

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