U.S. Department of the Interior
U.S. Geological Survey

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Army National Guard and the
Air Force Center for Engineering and the Environment

Scientific Investigations Map 3233
Pamphlet accompanies map

Introduction

This report presents a topographic map of the bedrock surface beneath western Cape Cod, Massachusetts, that was prepared for use in groundwater-flow models of the Sagamore lens of the Cape Cod aquifer. The bedrock surface of western Cape Cod had been characterized previously through seismic refraction surveys and borings drilled to bedrock. The borings were mostly on and near the Massachusetts Military Reservation (MMR). The bedrock surface was first mapped by Oldale (1969), and mapping was updated in 2006 by the Air Force Center for Environmental Excellence (AFCEE, 2006). This report updates the bedrock-surface map with new data points collected by using a passive seismic technique based on the horizontal-to-vertical spectral ratio (HVSR) of ambient seismic noise (Lane and others, 2008) and from borings drilled to bedrock since the 2006 map was prepared.

The HVSR method is based on a relationship between the resonance frequency of ambient seismic noise as measured at land surface and the thickness of the unconsolidated sediments that overlie consolidated bedrock. The HVSR method was shown by Lane and others (2008) to be an effective method for determining sediment thickness on Cape Cod owing to the distinct difference in the acoustic impedance between the sediments and the underlying bedrock. The HVSR data for 164 sites were combined with data from 559 borings to bedrock in the study area to create a spatially distributed dataset that was manually contoured to prepare a topographic map of the bedrock surface. The interpreted bedrock surface generally slopes downward to the southeast as was shown on the earlier maps by Oldale (1969) and AFCEE (2006). The surface also has complex small-scale topography characteristic of a glacially eroded surface. More information about the methods used to prepare the map is given in the pamphlet that accompanies this plate.

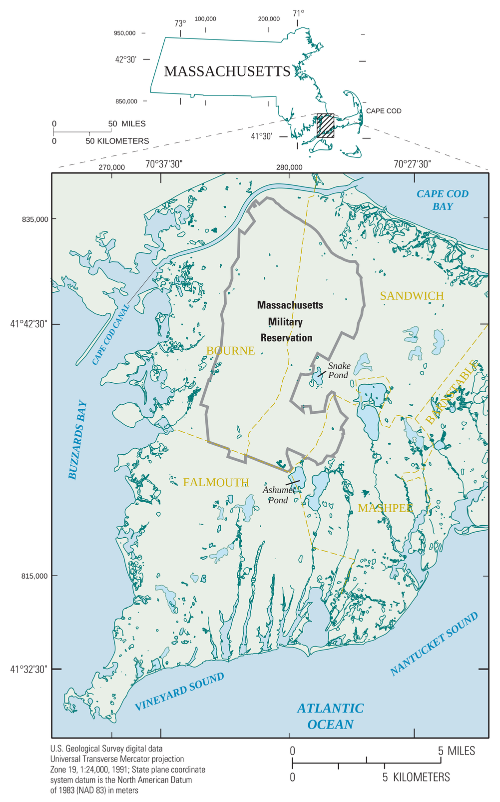

Figure 1. The area of the map presented in this report is on western Cape Cod, Massachusetts, and includes the Massachusetts Military Reservation and all or parts of five surrounding towns. The study area is on unconsolidated glacial drift deposits that consist of glaciofluvial sand and gravel outwash overlying glaciolacustrine sand and silt, with sandy moraines near the northern and western coasts. The underlying bedrock is primarily granodiorite (Oldale and Barlow, 1986; Oldale, 1992).

Figure 2. The horizontal-to-vertical spectral-ratio (HVSR) method uses a single broadband, three-component seismometer *A*, to record ambient seismic noise from the earth's surface. Ambient seismic noise is composed of microtremors caused by ocean waves, wind, rainfall, and anthropogenic sources such as traffic and industry (Ibs-von Seht and Wohlenberg, 1999). The HVSR method works best at locations like Cape Cod where generally homogeneous, unconsolidated sediments overlie consolidated bedrock (Lane and others, 2008). At each measurement site, the seismometer *B*, was placed firmly on the ground to ensure sufficient coupling with the earth, and data were collected for a minimum of 30 minutes.

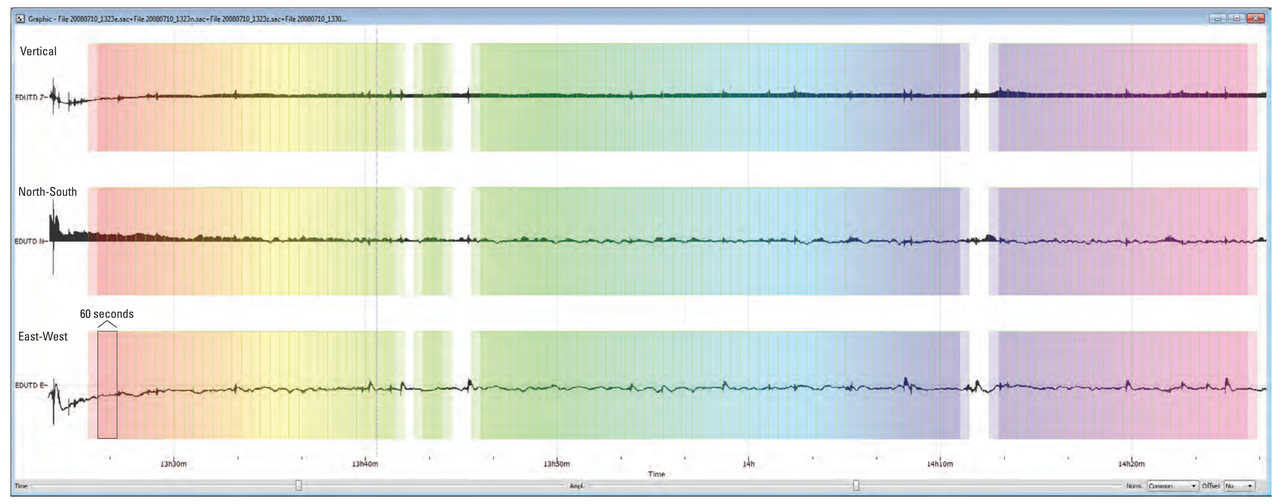

Figure 3. The graphical representation of the raw data to obtain the depth to bedrock is shown for site 00MW0584 (location shown in fig. 5). The graph was prepared by using the computer program Geopsy version 2.7.0 (Geopsy, 2011). The horizontal scale represents time, and the vertical scale represents the amplitudes of the data collected for seismic components in three perpendicular directions: vertical (Z), north-south (N), and east-west (E). The raw data were divided into time intervals 60 seconds long that overlap adjacent intervals by 30 seconds each. The small spikes in amplitude above the generally smooth traces were caused by high-amplitude noise disturbances such as the nearby passage of individual vehicles or pedestrians. Data from these intervals, which are not colored, were removed prior to further data processing.

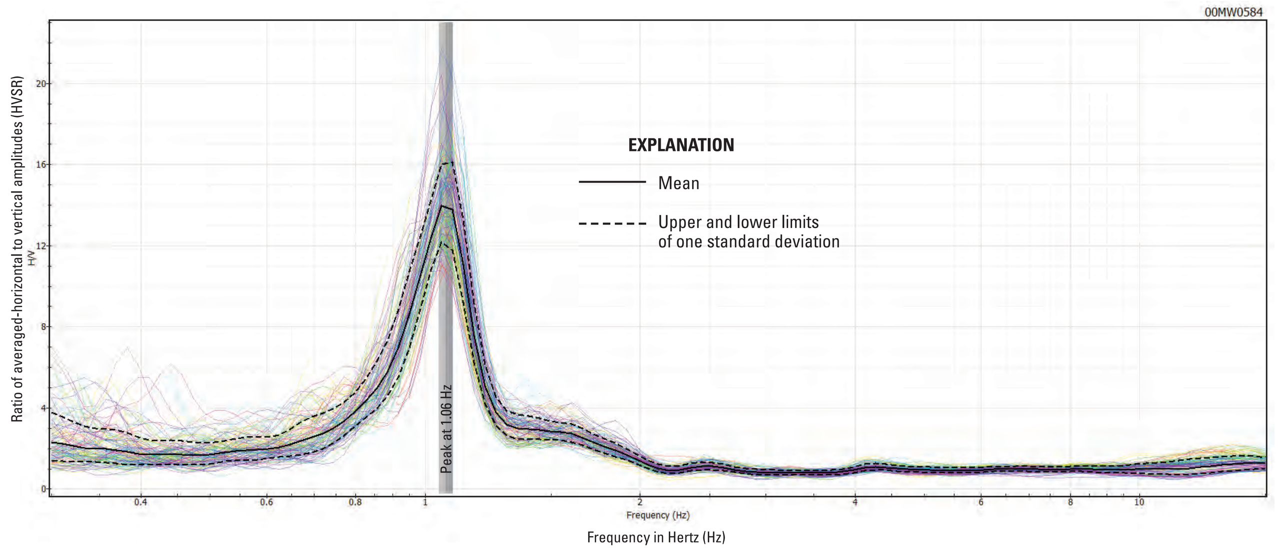

Figure 4. The fundamental resonance frequency at a site was determined by a spectral analysis of the horizontal and vertical components of the recorded seismic noise. The amplitudes of the spectra of the vertical and two horizontal components of the microtremors for each of the 60-second time intervals were calculated by the Geopsy program. The average of the amplitudes for the horizontal components was divided by the vertical component, and this ratio (the HVSR) was plotted as a function of frequency. The colored lines in this graphical output from the Geopsy program correspond to the similarly colored time intervals shown in figure 3. The fundamental resonance frequency in this example from site 00MW0584 is 1.06 Hz defined by the peak in the average HVSR plot (average and standard deviation shown by the solid and dashed black lines, respectively). An empirical equation (see accompanying pamphlet) developed for Cape Cod by Lane and others (U.S. Geological Survey, written commun., 2011) was used to estimate the sediment thickness from the fundamental resonance frequency. The resulting thickness was subtracted from the land-surface altitude to obtain the bedrock-surface altitude.

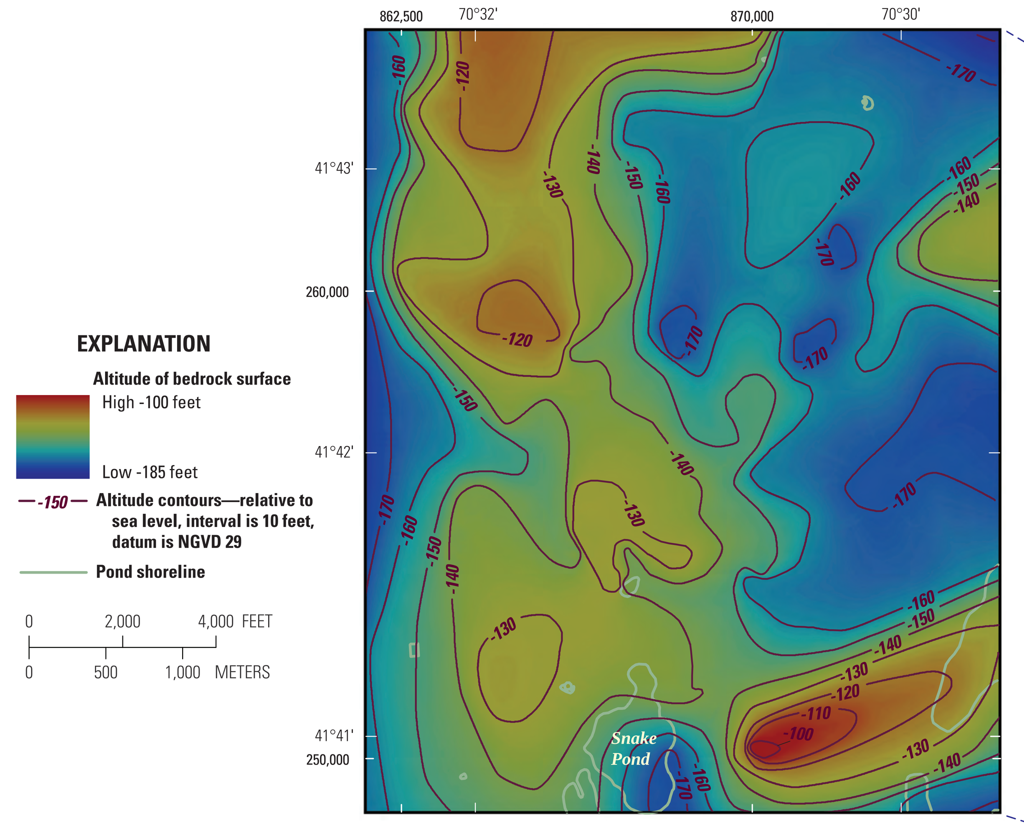

Figure 6. The topographic map of the bedrock surface beneath the area near Snake Pond was prepared with a 10-foot contour interval because of the closely spaced data points obtained mostly from geologic borings in this area. The location of the map is shown in figure 5.

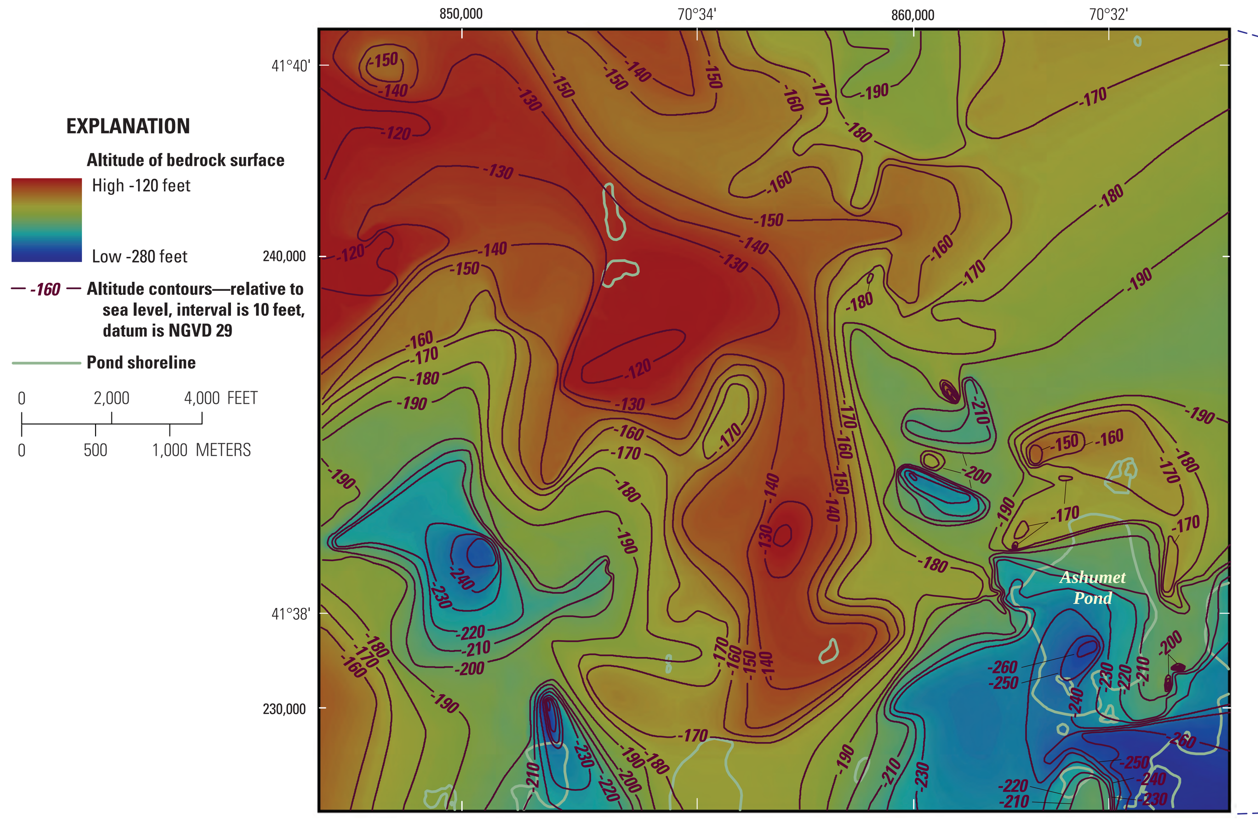

Figure 7. The topographic map of the bedrock surface beneath the area near Ashumet Pond was prepared with a 10-foot contour interval because of the closely spaced data points obtained mostly from geologic borings in this area. The location of the map is shown in figure 5.

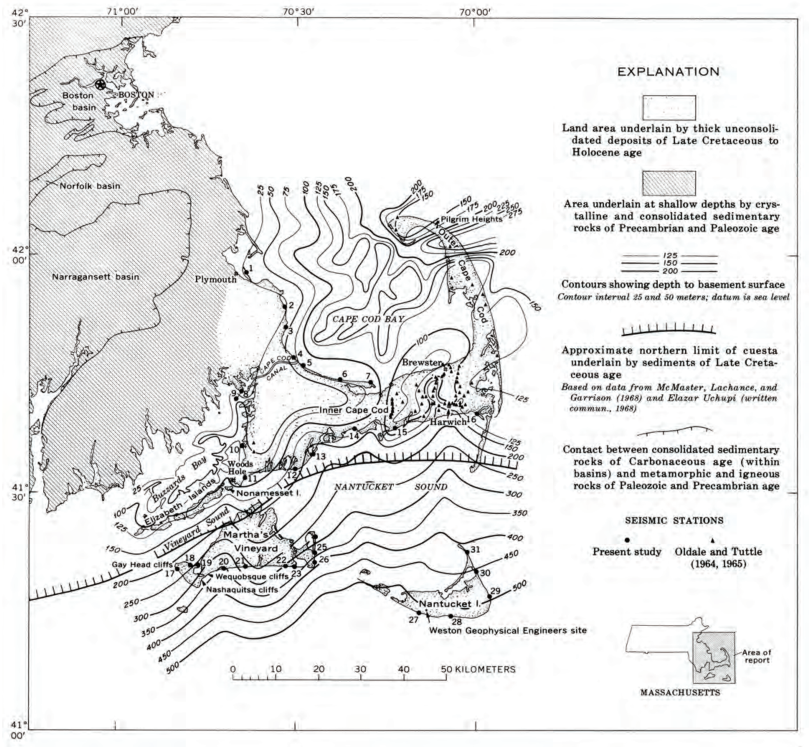

Figure 8. The interpreted representation of the bedrock surface in figure 5 is similar in its general features to Oldale's 1969 map shown here and the map produced by the Air Force Center for Environmental Excellence (AFCEE) (2006) (not shown). In all three maps, the bedrock surface generally slopes downward to the southeast toward Nantucket Sound. The maps similarly show lobes of shallower bedrock extending from the vicinity of the Cape Cod Canal to the east toward Barnstable and to the south toward Woods Hole. The bedrock surface is more than 47 feet below NGVD 29 (sea level) throughout the mapped area and therefore does not crop out at the land surface. The general trends in altitude shown on the small-scale map (fig. 5) may reflect preglacial drainage patterns in the bedrock surface. The large-scale maps in figs. 6 and 7, however, show a surface whose altitude varies considerably over a small area. Small-scale variations, including closed depressions in the bedrock surface, are consistent with a glacially eroded bedrock surface (B.D. Stone, U.S. Geological Survey, written commun., 2011).

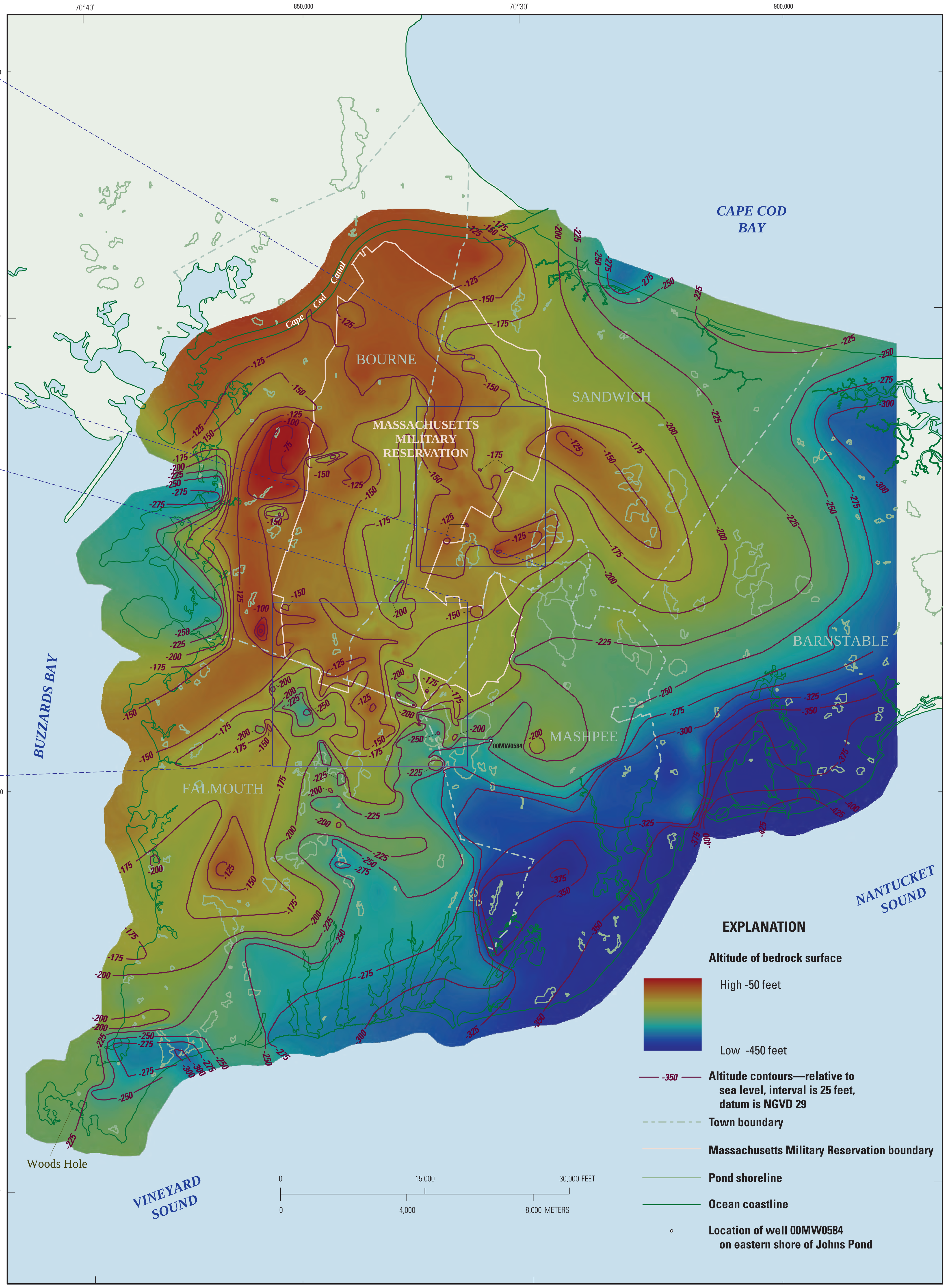

Figure 5. The bedrock-surface altitudes from the HVSR survey, seismic refraction surveys, and geologic borings that reportedly hit bedrock were plotted on a map of western Cape Cod and hand contoured with a 25-foot contour interval. This interval is consistent with an estimated uncertainty in the bedrock-surface altitudes from the HVSR method of about 10 percent of the depth to bedrock, or about 20–30 feet over much of the area. The altitudes from the borings have an estimated uncertainty of about 5 feet. The location of the map is shown in figure 1. MMR, Massachusetts Military Reservation.

References cited on this plate are listed in the accompanying pamphlet.

Suggested citation:
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Bedrock Topography of Western Cape Cod, Massachusetts, Based on Bedrock Altitudes from Geologic Borings and Analysis of Ambient Seismic Noise by the Horizontal-to-Vertical Spectral-Ratio Method

By
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