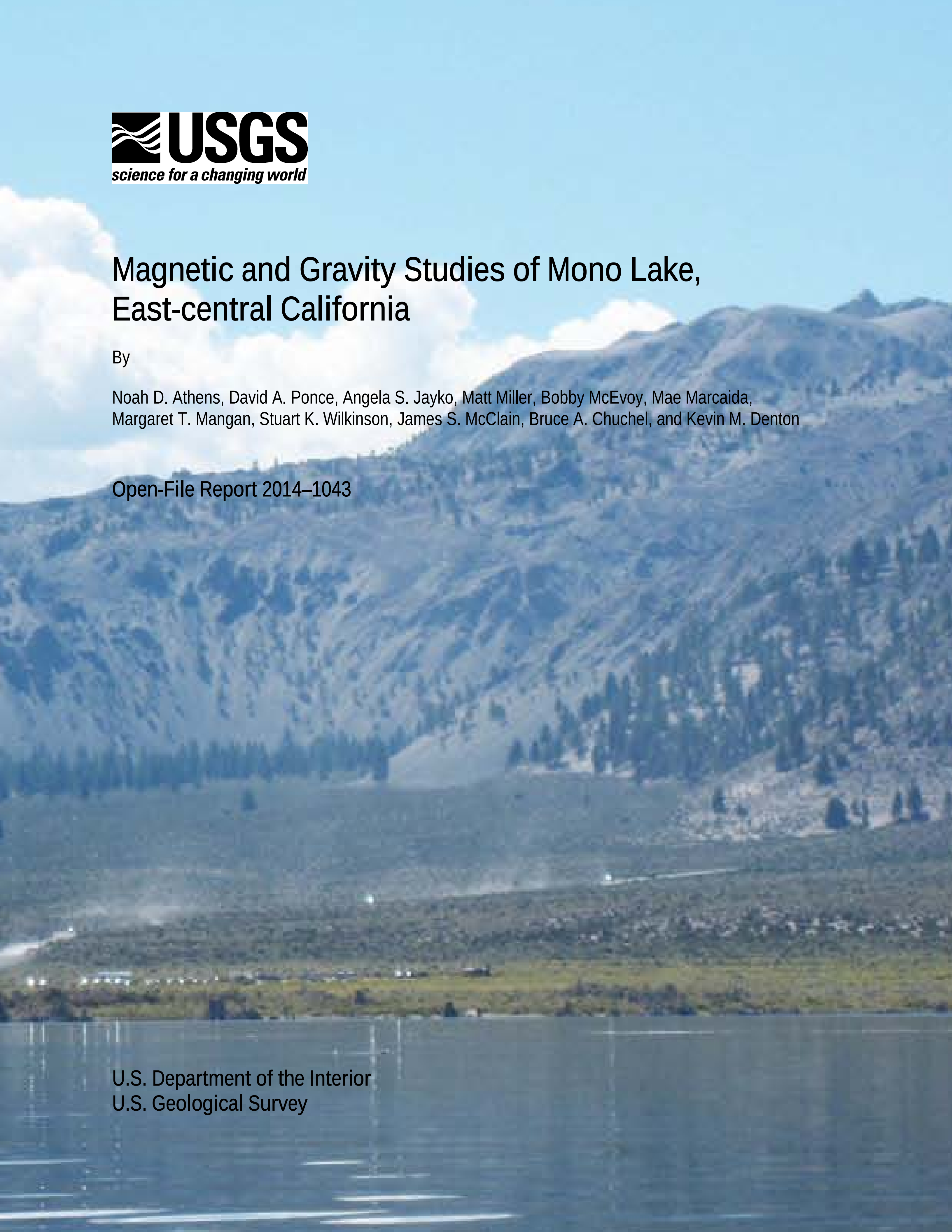

Magnetic and Gravity Studies of Mono Lake, East-central California

By

Noah D. Athens, David A. Ponce, Angela S. Jayko, Matt Miller, Bobby McEvoy, Mae Marcaida, Margaret T. Mangan, Stuart K. Wilkinson, James S. McClain, Bruce A. Chuchel, and Kevin M. Denton

Open-File Report 2014–1043

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Cover: View looking south across Mono Lake,
east-central California. (Photograph by D.A. Ponce).

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SALLY JEWELL, Secretary

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Tables 2-4 are available in Excel format and can be downloaded at: *http://pubs.usgs.gov/of/2014/1043*

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Magnetic and Gravity Studies of Mono Lake, East-central California

By

Noah D. Athens[1], David A. Ponce[1], Angela S. Jayko[1], Matt Miller[2], Bobby McEvoy[2], Mae Marcaida[1], Magaret T. Mangan[1], Stuart K. Wilkinson[1], James S. McClain[2], Bruce A. Chuchel[1], and Kevin M. Denton[1]

Introduction

From August 26 to September 5, 2011, the U.S. Geological Survey (USGS) collected more than 600 line-kilometers of shipborne magnetic data on Mono Lake, 20 line-kilometers of ground magnetic data on Paoha Island, 50 gravity stations on Paoha and Negit Islands, and 28 rock samples on Paoha and Negit Islands, in east-central California (fig. 1). Magnetic and gravity investigations were undertaken in Mono Lake to study regional crustal structures and to aid in understanding the geologic framework, in particular regarding potential geothermal resources and volcanic hazards throughout Mono Basin. Furthermore, shipborne magnetic data illuminate local structures in the upper crust beneath Mono Lake where geologic exposure is absent.

Magnetic and gravity methods, which sense contrasting physical properties of the subsurface, are ideal for studying Mono Lake. Exposed rock units surrounding Mono Lake consist mainly of Quaternary alluvium, lacustrine sediment, aeolian deposits, basalt, and Paleozoic granitic and metasedimentary rocks (Bailey, 1989). At Black Point, on the northwest shore of Mono Lake, there is a mafic cinder cone that was produced by a subaqueous eruption around 13.3 ka. Within Mono Lake there are several small dacite cinder cones and flows, forming Negit Island and part of Paoha Island, which also host deposits of Quaternary lacustrine sediments. The typical density and magnetic properties of young volcanic rocks contrast with those of the lacustrine sediment, enabling us to map their subsurface extent.

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Physical-Property , Magnetic, and Gravity Data

Physical-Property Data

We collected 28 rock samples on Paoha and Negit Islands, most of which are trachydacite from the volcanic rock outcrops on the eastern margin of Paoha Island (fig. 1). Physical-property data are summarized in table 1 and provided in full in table 2. The data include station identifier, geographic coordinates, rock type, density, and magnetic susceptibility. Densities were determined using the buoyancy method and an electronic balance, and magnetic-susceptibility measurements were made using a Kappameter® KT-5. Each sample was weighed

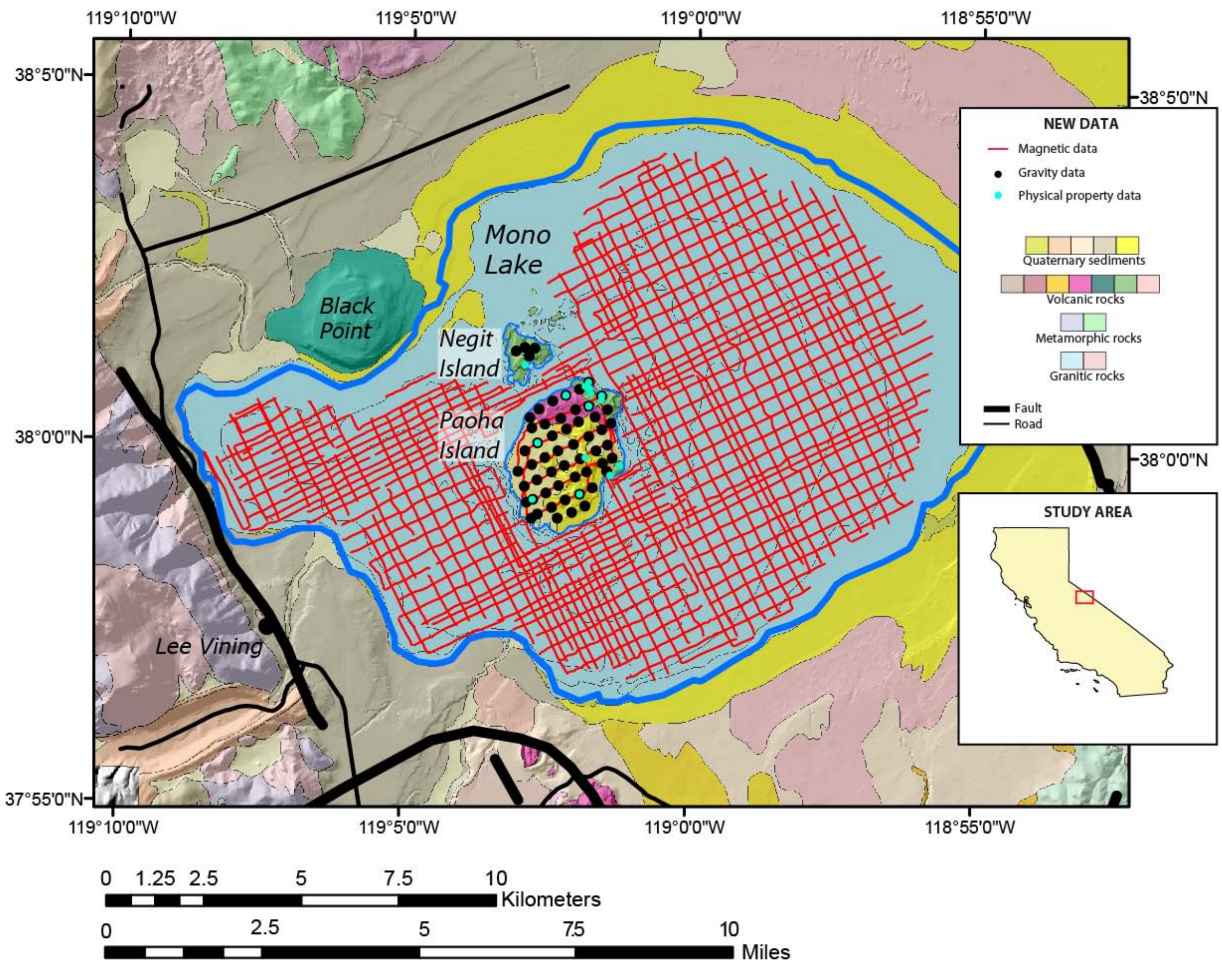

Figure 1. Geologic map of Mono Lake (Bailey, 1989), east-central California, showing locations of acquired shipborne magnetic data and ground magnetic data, gravity data, and physical-property data.

in air (*Wa*), saturated and submerged in water (*Ww*), and saturated in air (*Was*). The grain, saturated-bulk, and dry-bulk densities were computed using the following formulas:

Grain density = 1,000 kg/m^3 x *Wa*/(*Wa*-*Ww*),

Saturated-bulk density = 1,000 kg/m^3 x *Was*/(*Was*-*Ww*), and

Dry-bulk density = 1,000 kg/m^3 x *Wa*/(*Was*-*Ww*).

Table 1. Physical properties of rocks collected on Paoha and Negit Islands, Mono Lake, east-central California.

Rock type	N	Grain density kg/m^3	Range			N	Saturated-bulk density kg/m^3	Range			N	Dry-bulk density kg/m^3	Range			N	Magnetic susceptibility x10^{-3} SI	Range		
Poaha Island																				
Pumice	2	1063	1034	-	1092	2	1048	1027	-	1068	2	825	809	-	841	2	0.360	0.180	-	0.540
Rhyolite	1	2541	--		--	1	2329	--		--	1	2191	--		--	1	1.520	--		--
Trachydacite	17	2077	1493	-	2545	16	1987	1486	-	2491	16	1926	1434	-	2485	17	2.978	0.780	-	7.120
Negit Island																				
Trachydacite	5	2389	2185	-	2558	3	2266	2175	-	2347	3	2258	2166		2339	5	6.808	5.670	-	9.030
N, number of samples																				

Magnetic Data

Shipborne Magnetic Data

About 626 line-kilometers of shipborne magnetometer data were collected along approximately northeast and northwest-trending traverses shown in figure 1. Magnetometer and Global Positioning System (GPS) data were collected simultaneously at 1-second intervals using a Geometrics® G858 cesium vapor magnetometer attached to a wooden and aluminum pole extended about 2 m in front of the bow. The height of the magnetometer above the water surface was about 1 m. A portable Geometrics® G856 proton-precession base-station magnetometer was used to record diurnal variations of the Earth's magnetic field during the shipborne magnetometer surveys and was installed on the western shore of the lake.

The boat used for the shipborne survey, constructed of wood with a single outboard engine, was relatively non-magnetic. Figure 2 shows the boat and magnetic-survey system. During field operations, shipborne magnetic data were recorded and viewed in real-time using Geometrics® MagLog software. Raw magnetic data were downloaded and processed using

Geometrics® MagMap2000 software, where magnetometer and GPS data were merged. The location of the magnetometer was recorded using a Trimble® nonmagnetic Ag132 GPS receiver mounted on an aluminum frame attached to the cabin of the boat. The Ag132 receiver has real-time differential correction capabilities using an Omnistar satellite system, resulting in submeter horizontal accuracy. The data were collected in geographic coordinates, and magnetic field values are expressed in nanoteslas (nT). Shipborne data were corrected for diurnal variations, filtered to remove cultural noise, leveled, and corrected for heading effects due to the boat's magnetic field.

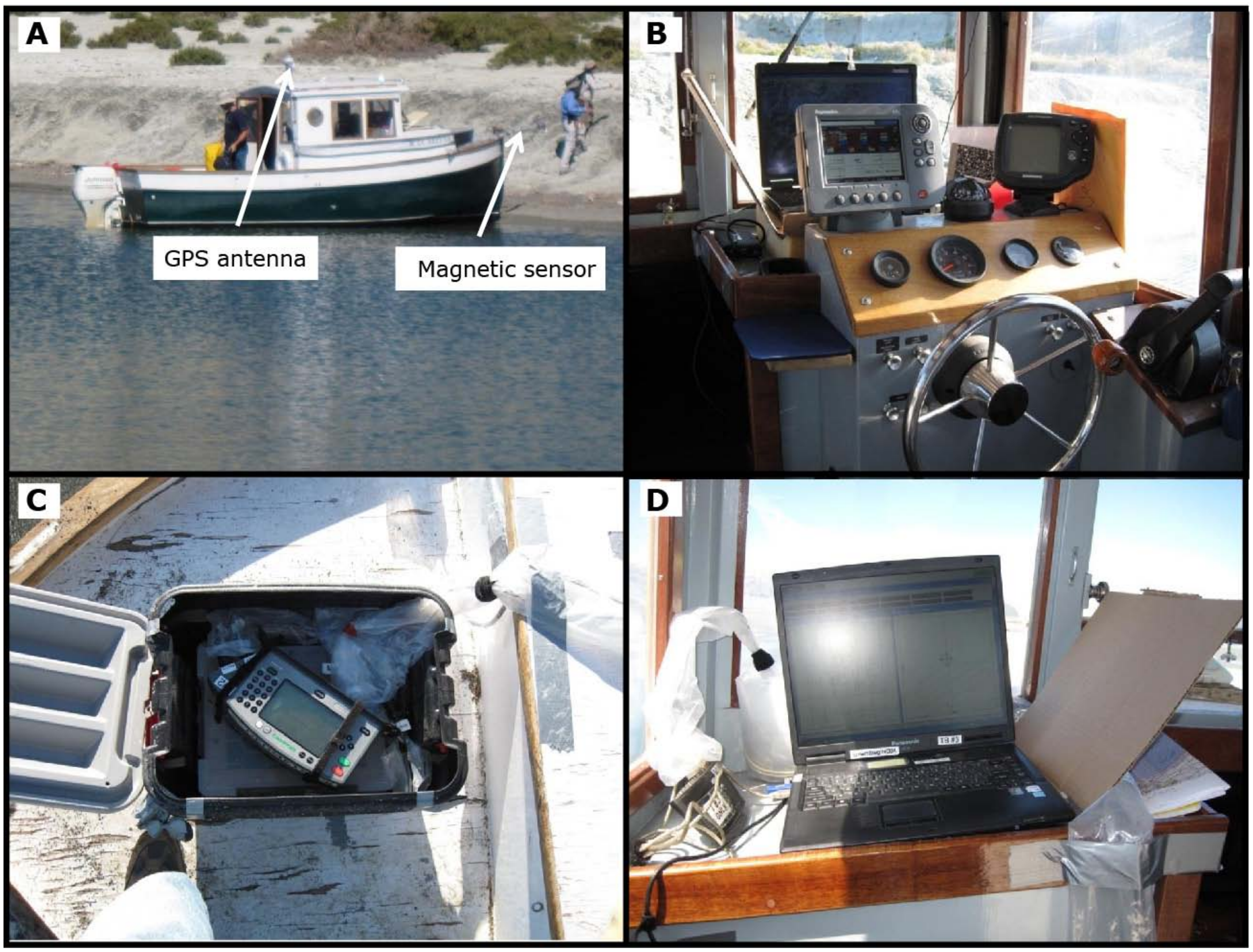

Figure 2. Shipborne magnetic system. *A*, The magnetic sensor is located 2 m in front of the bow in order to be away from the outboard engine. *B*, PC laptop and depth finder used for navigating the survey area. PC laptop runs National Geographic's navigation software TOPO!, which is synchronized to a handheld GPS instrument. *C*, Data logger that streams magnetic readings and GPS locations to *D*, laptop PC for viewing and storing data.

Ground Magnetic Data

About 22 line-kilometers of ground magnetic data were collected along six approximately northeast-trending traverses across Paoha Island (fig. 1). These traverses were collected using a Geometrics® G858 cesium vapor magnetometer with the same survey and GPS specifications as the shipborne magnetometer survey. The height of the magnetometer above the ground surface was about 2 m. Analogous to the shipborne magnetic processing, diurnal variations recorded by the base-station magnetometer were removed, and the data were filtered to remove cultural noise. Individual lines were not leveled with one another. Combined shipborne and gound magnetic data are provided in table 3.

Gravity Data

Gravity data were collected along approximately northeast-trending traverses and consist of 56 new stations on Paoha and Negit Islands (fig. 1). All gravity data were tied to a primary base station LEEVIN at the U.S. Post Office in Lee Vining, California, at latitude 37°57.34'N. and longitude 119°07.14'W (NAD27) with an observed gravity value of 979,348.30 mGal (Appendix). Gravity data are provided in table 4.

Gravity data were reduced using standard gravity methods (for example, Dobrin and Savit, 1988; Blakely, 1995) that include the following corrections: (a) Earth-tide correction, which corrects for gravitational effects of the moon and sun; (b) instrument-drift correction, which compensates for drift in the instrument’s spring; (c) latitude correction, which accounts for the variation of the Earth’s gravity with latitude; (d) free-air correction, which accounts for the variation in gravity due to elevation relative to sea level; (e) Bouguer correction, which corrects for the attraction of material between the station and sea level; (f) curvature correction, which corrects the Bouguer correction for the effect of the Earth’s curvature; (g) terrain correction, which removes the effect of topography to a radial distance of 167 km around the station; and (h) isostatic correction, which removes long-wavelength variations in the gravity field related to the compensation at depth of topographic loads at the Earth’s surface.

A Scintrex CG-5 gravity meter was used in this survey. Conversion of meter readings to gravity units for the Scintrex CG-5 gravity meter were made using factory calibration constants, as well as a secondary calibration factor determined by multiple gravity readings over the Mt. Hamilton calibration loop east of San Jose, Calif. (Barnes and others, 1969). Observed gravity values were corrected for a time-dependent linear drift between successive base readings and 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 (1942, p. 65) formula for the free-air correction. Bouguer, curvature, and terrain corrections were added to the free-air anomaly 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 anomaly assuming an Airy-Heiskanen model for isostatic compensation of topographic loads (Jachens and Roberts, 1981), with an assumed nominal sea-level crustal thickness of 25 km, a crustal density of 2,670 kg/m^3, and a density contrast across the base of the crust of 400 kg/m^3. Gravity values are expressed in mGal (milligal), a unit of acceleration or gravitational force per mass equal to 10^{-5} m/s^2.

Gravity station locations and elevations were obtained using a Trimble® GeoXH dual-frequency GPS instrument. Post-processing of GPS positions using Continuously Operating Reference Station (CORS) data results in submeter horizontal and vertical accuracy.

Terrain corrections, which account for the gravity effect of topographic variation near a gravity station, were computed using a combination of manual and digital methods. Terrain corrections consisted of a three-part process: (1) the innermost or field terrain correction, (2) inner-zone terrain correction, and (3) outer-zone terrain correction. The innermost terrain corrections were estimated in the field and extend from the station to a radial distance of 68 m, equivalent to Hayford and Bowie's (1912) zone B. Inner-zone terrain corrections were estimated from digital elevation models (DEMs) with 10- or 30-m resolutions derived from USGS 7.5' topographic maps and extend from a radial distance of 68 m out to 2 km (D. Plouff, USGS, unpub. software, 2006). Outer-zone terrain corrections, from a radial distance of 2–167 km, were computed by using a DEM derived from USGS 1:250,000-scale topographic maps and an automated procedure based on geographic coordinates (Plouff, 1966; Plouff, 1977; Godson and Plouff, 1988). Digital-terrain corrections were calculated by computing the gravity effect of each grid cell in the DEM using the distance and difference in elevation of each grid cell from the gravity station.

Shipborne Magnetic-Data Processing

The local base-station data were validated by comparing them to the Fresno Magnetic Observatory records obtained from the International Real-time Magnetic Observatory Network (INTERMAGNET) (Kerridge, 2001) before removing the diurnal variations from the survey data. Magnetic anomalies were calculated by subtracting an International Geomagnetic Reference Field (IGRF) (Finlay and others, 2010) appropriate for the time of the survey.

A heading correction (fig. 3) was applied to the shipborne magnetic data to account for the systematic shift in the magnetic readings that is due to the magnetic field produced by the boat and the orientation of the boat (for example, Athens and others, 2011). The heading correction was determined by piloting the boat over the same point while traveling in the direction of the survey lines: 65º, 155º, 245º, and 335º. The difference between the average value

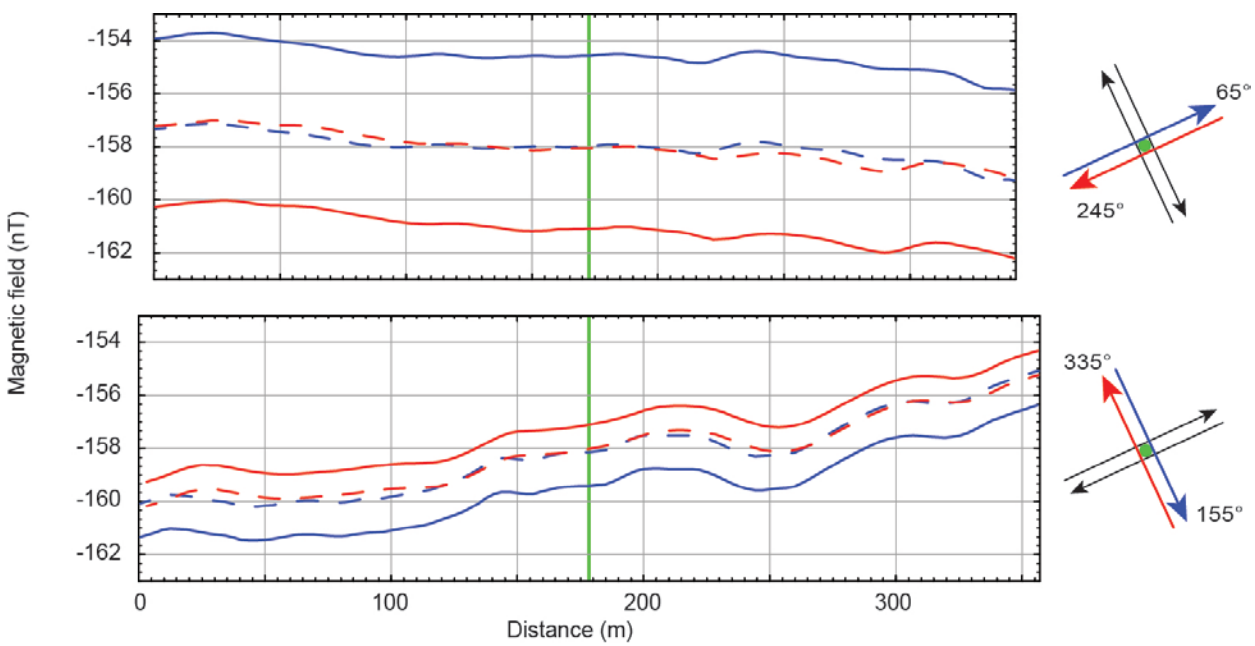

Figure 3. Shipborne magnetic system heading test. Four profiles were collected while traveling in the direction of survey lines (65º, 155º, 245º, and 335º) forming a cross pattern. Profiles in opposite directions are compared in order to determine the systematic shift in magnetic values due to the boat's magnetic field. Solid lines indicate magnetic-field values before the heading correction was applied, and dashed lines indicate magnetic-field values after the heading correction. Green line, intersection point. Heading-correction values applied—65º, -3.425 nT; 155º, +1.32 nT; 245º, +3.035 nT; and 335º, -0.95 nT.

at the intersection point and the measured value for each direction is the heading correction. The heading correction values that were applied to the survey data are summarized in figure 3. Magnetic readings that were not collected while in the directions of the main survey lines were removed from the survey.

After applying the heading correction, the difference in magnetic anomaly values where two survey lines cross was calculated. Of the 958 crossing values in the survey, approximately 95 percent were below 5 nT, indicating that the shipborne magnetic readings are repeatable and have small crossing errors. The crossing values that were above 5 nT were from areas of high magnetic gradients where small GPS location differences result in greater crossing mismatches.

A low-pass filter with a wavelength cutoff of 50 m was applied to smooth high-frequency noise (~2 nT) caused by the movement of the boat on the water. Leveling was applied to the survey data, and the shipborne survey was combined with the ground magnetic survey.

Discussion

Magnetic anomalies reflect changes in the Earth’s magnetic field and are typically used to infer lateral variations in the magnetization of rocks. Short-wavelength, high-amplitude magnetic anomalies are usually caused by volcanic rocks that are moderately to strongly magnetic. Because of the dipolar nature of magnetic sources, magnetic highs are typically accompanied by an associated magnetic low at the latitude of our study area; the location of the highs and lows reflects properties of the magnetization vector.

Magnetic highs in the study area occur to the east and west of Mono Lake (fig. 4) where pre-Tertiary basement is exposed. Magnetic data indicate that Mono Lake is dominated by three prominent magnetic anomalies that are, from west to east, a magnetic high along the northwest part of the lake associated with the moderately magnetic basalt cinder cone at Black Point (Bailey, 1989), a magnetic high and accompanying low associated with the young volcanic centers at Paoha and Negit Islands (Bailey, 1989), and a broad magnetic high along the eastern margin of the lake that is probably associated with moderately magnetic granitic basement rocks at depth. Because volcanic rocks exposed at the surface of Paoha and Negit Islands are weakly magnetic (table 1), magnetic data suggest that more mafic volcanic rocks probably occur at depth and are the probable source of the anomaly. A fault may be imaged in the northeastern part of the lake where a laterally offset magnetic anomaly is evident.

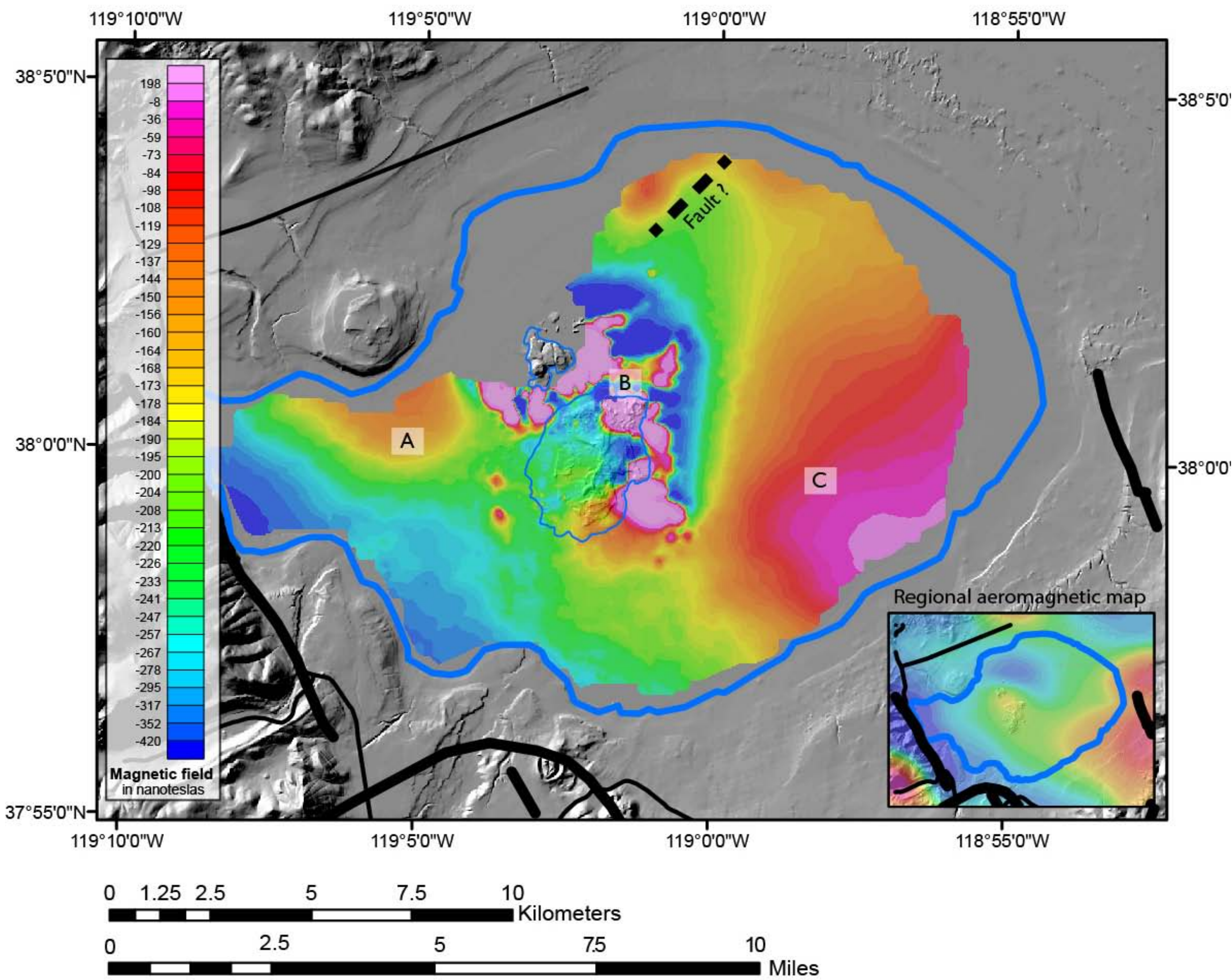

Figure 4. Shipborne and ground magnetic map of Mono Lake, east-central California. Prominent magnetic anomalies include *A,* a magnetic high associated with a basaltic cinder cone; *B,* a magnetic high and accompanying low associated with young volcanic centers at Paoha and Negit Islands; and *C,* a broad magnetic high probably associated with granitic basement rock. Inset is a regional aeromagnetic map of the same area that shows general agreement of magnetic anomalies (Roberts and Jachens, 1999).

Isostatic gravity anomalies (fig. 5) primarily reflect lateral density variations in the middle to upper crust, and they can be used to infer the subsurface geology and structure. Gravity anomalies can reveal variations in lithology and features, such as calderas, deep sedimentary basins, and faults, all of which may play a role in defining the geologic framework of the Mono Basin area.

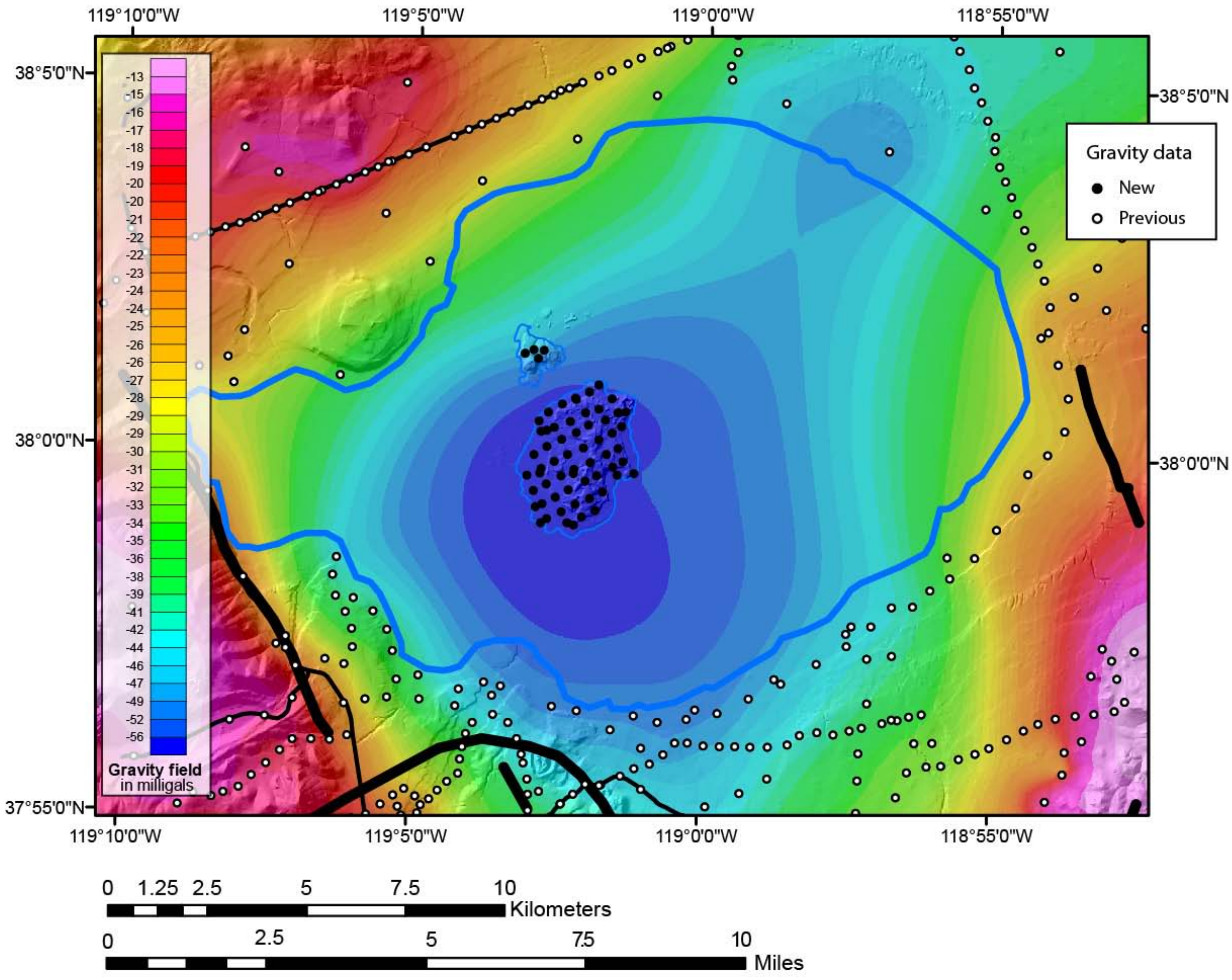

Figure 5. Isostatic gravity map of the study area in east-central California. Land-based gravity coverage is limited to the area surrounding the Mono Lake and Paoha and Negit Islands. Previous gravity data were published in two compilations (Snyder and others, 1981; Ponce, 1997).

Within Mono Lake, gravity-station control is poor because land-based gravity stations are limited to Paoha and Negit Islands. The gravity low in the basin (fig. 5) reflects a moderately deep sedimentary basin filled with low-density lacustrine and volcanic deposits. Isostatic gravity data indicate the central part of Mono Lake corresponds approximately to a 30-mGal gravity low, yielding a basin depth of about 2.2 km, assuming a density contrast of 0.4 g/cm^3 between lake-fill deposits and bedrock, and using a semi-infinite slab approximation of the basin floor (Nettleton, 1976).

The physical property variations of the rocks that underlie this region are well suited to geophysical investigations. The contrast in density and magnetic properties between pre-Tertiary crystalline basement and the overlying Quaternary volcanic rocks and unconsolidated alluvium, for example, produces a distinctive pattern of gravity and magnetic anomalies. These anomalies can be used to infer subsurface geologic structure and aid in understanding the geologic framework of Mono Lake and the entire Mono Basin.

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Appendix

GRAVITY BASE STATION

NAME	CITY/STATE
LEEVIN	Lee Vining, California
LATITUDE/LONGITUDE/ELEVATION (NAD27/29) 37°57.34' 119°07.14' 6794.9 ft (GPS)	ACIC Reference No. N.A.
OBSERVED GRAVITY (IGSN71) 979,348.30 milligals	(n=2, from Mammoth Lakes MLEQB1)

DESCRIPTION

The station is located at the U.S. Post Office in Lee Vinning, Califonria. The station is outside the front (north side) of the post office, at the left (east) corner of the building, on a cement apron. Read the meter in the corner of the building and the edge of the cement arpon, read the meter facing the building (south).

PHOTO

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