U.S. Department of the Interior
National Park Service
Natural Resource Stewardship and Science Directorate
Geologic Resources Division

Lava Beds National Monument

GRI Ancillary Map Information Document

Produced to accompany the Geologic Resources Inventory (GRI) Digital Geologic Data for Lava Beds National Monument

labe_geology.pdf

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Geologic Resources Inventory Map Document for Lava Beds National Monument

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Geologic Resources Inventory Map Document

Lava Beds National Monument, California

Document to Accompany Digital Geologic-GIS Data

labe_geology.pdf

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This document has been developed to accompany the digital geologic-GIS data developed by the Geologic Resources Inventory (GRI) program for Lava Beds National Monument, California (LABE).

Attempts have been made to reproduce all aspects of the original source products, including the geologic units and their descriptions, geologic cross sections, the geologic report, references and all other pertinent images and information contained in the original publication.

National Park Service (NPS) Geologic Resources Inventory (GRI) Program staff have assembled the digital geologic-GIS data that accompanies this document.

For information about the status of GRI digital geologic-GIS data for a park contact:

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About the NPS Geologic Resources Inventory Program

Background

Recognizing the interrelationships between the physical (geology, air, and water) and biological (plants and animals) components of the Earth is vital to understanding, managing, and protecting natural resources. The Geologic Resources Inventory (GRI) helps make this connection by providing information on the role of geology and geologic resource management in parks.

Geologic resources for management consideration include both the processes that act upon the Earth and the features formed as a result of these processes. Geologic processes include: erosion and sedimentation; seismic, volcanic, and geothermal activity; glaciation, rockfalls, landslides, and shoreline change. Geologic features include mountains, canyons, natural arches and bridges, minerals, rocks, fossils, cave and karst systems, beaches, dunes, glaciers, volcanoes, and faults.

The Geologic Resources Inventory aims to raise awareness of geology and the role it plays in the environment, and to provide natural resource managers and staff, park planners, interpreters, researchers, and other NPS personnel with information that can help them make informed management decisions.

The GRI team, working closely with the Colorado State University (CSU) Department of Geosciences and a variety of other partners, provides more than 270 parks with a geologic scoping meeting, digital geologic-GIS map data, and a park-specific geologic report.

Products

Scoping Meetings: These park-specific meetings bring together local geologic experts and park staff to inventory and review available geologic data and discuss geologic resource management issues. A summary document is prepared for each meeting that identifies a plan to provide digital map data for the park.

Digital Geologic Maps: Digital geologic maps reproduce all aspects of traditional paper maps, including notes, legend, and cross sections. Bedrock, surficial, and special purpose maps such as coastal or geologic hazard maps may be used by the GRI to create digital Geographic Information Systems (GIS) data and meet park needs. These digital GIS data allow geologic information to be easily viewed and analyzed in conjunction with a wide range of other resource management information data.

For detailed information regarding GIS parameters such as data attribute field definitions, attribute field codes, value definitions, and rules that govern relationships found in the data, refer to the NPS Geology-GIS Data Model document available at: http://science.nature.nps.gov/im/inventory/geology/GeologyGISDataModel.cfm

Geologic Reports: Park-specific geologic reports identify geologic resource management issues as well as features and processes that are important to park ecosystems. In addition, these reports present a brief geologic history of the park and address specific properties of geologic units present in the park.

For a complete listing of Geologic Resource Inventory products and direct links to the download site visit the GRI publications webpage http://www.nature.nps.gov/geology/inventory/gre_publications.cfm

GRI geologic-GIS data is also available online at the NPS Data Store Search Application: http://irma.nps.gov/App/Reference/Search. To find GRI data for a specific park or parks select the appropriate park

(s), enter “GRI” as a Search Text term, and then select the Search Button.

For more information about the Geologic Resources Inventory Program visit the GRI webpage: http://www.nature.nps.gov/geology/inventory, or contact:

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GRI Digital Map and Source Map Citations

The GRI digital geologic-GIS map for Lava Beds National Monument, California (LABE):

GRI Digital Geologic Map of the Lava Beds National Monument and Vicinity, California (*GRI MapCode LABE*)

Donnelly-Nolan, J.M., 2010, Geologic Map of Medicine Lake Volcano, Northern California, U.S. Geological Survey, Scientific Investigations Map SIM-2927, 1:50,000 scale. (Lava Beds). (*GRI Source Map ID 7411*).

> The Medicine Lake volcano source publication (SIM-2927) consists of a GIS database, PDF files for plotting, 31 photographs, and links to related information. The GRI map and document includes all of the Medicine Lake volcano source publication. Lava Beds National Monument is a portion of the Medicine Lake volcano occurring in the north-central part of the map (see Lava Beds Index).

Additional References:

Donnelly-Nolan, Julie M., 2006, Chemical Analyses and K-Ar Ages of Samples from 13 Drill Holes, Medicine Lake Volcano, California, U.S. Geological Survey, Open-File Report OF-2006-1041. (*GRI Source Map ID 75219*).

> USGS open-file report OF-2006-1041 provided drill hole completion data for 13-drill holes completed within the Medicine Lake volcano. Drill hole locations were included in the USGS GIS data. The report tables include drill hole completion information, major element and EDXRF trace element data, Flame photometry and INAA data, and K-Ar ages on drill core samples. The complete report is available as a separate PDF document (*OFR 2006-1041*)

Donnelly-Nolan, Julie M., And Lanphere, Marvin A., 2005, Argon Dating at and near Medicine Lake Volcano, California: Results and Data, U.S. Geological Survey, Open-File Report OF-2005-1416. (*GRI Source Map ID 75220*).

> The USGS open-file report OF-2005-1416 provided K-Ar and 40Ar/39Ar ages and supplementary data. Geologic samples analyzed for Argon radiometric ages are included in the GIS data in the Geologic Sample Location feature class. The Geologic Sample Locations feature class includes samples analyzed for both argon radiometric ages and chemical results. Argon age sample locations were obtained from Table 1 of the report. Many of the geologic samples were collected from locations outside of the Medicine Lake volcano and Lava Beds National Monument. Because of limitations on the location information, the positional accuracy of the sample location is considered approximate.The complete report is available as a separate PDF document (OFR 2005-1416)

Donnelly-Nolan, Julie M., 2008, Chemical Analyses of Pre-Holocene Rocks from Medicine Lake Volcano and Vicinity, Northern California, U.S. Geological Survey, Open-File Report OF-2008-1094. (*GRI Source Map ID 75221*).

> The USGS open-file report OF-2008-1094 provided chemical analysis of more that 600 pre-Holocene rocks collected at or near Medicine Lake volcano. Geologic samples analyzed for chemical results are included in the GIS data in the Geologic Sample Location feature class. The

Geologic Sample Locations feature class includes samples analyzed for both chemical results and argon radiometric ages. Chemical result sample locations were obtained from Table 1 of the report. Many of the geologic samples were collected from units outside of the Medicine Lake volcano and Lava Beds National Monument. Because of limitations on the location information, the positional accuracy of the sample location is considered approximate.The complete report is available as a separate PDF document (OFR 2008-1094)

Table 1 of OFR 2008-1094 list analytical results and is available as separate MS Excel spreadsheet (Chemical Analyses Table 1)

Additional information pertaining to each source map is also presented in the GRI Source Map Information (LABEMAP) table included with the GRI geology-GIS data.

Map Unit List

The geologic units present in the digital geologic-GIS data produced for Lava Beds National Monument, California (LABE) are listed below. Units are listed with their assigned unit symbol and unit name (e.g., Hp - Pumice). Units are listed from youngest to oldest. No description for water or unmapped are provided. Information about each geologic unit is also presented in the GRI Geologic Unit Information (LABEUNIT) table included with the GRI geology-GIS data.

Radiocarbon ages, both measured number and calibrated age, are given in years before present (yr B. P.), where “present” is 1950 by convention.

The source authors divided the mapped area into 13 sectors radiating form a center at Medicine Lake. The sectors are used to locate units on the map and are referred to in the Unit Descriptions section and the text. The sector of each unit is given at the end of the Unit Description. (see Sector Location Map and on sheet 2 of source)

Mineral abbreviations: opx, orthopyroxene; cpx, clinopyroxene; pyx, pyroxene (seen in thin section but of uncertain composition); ol, olivine; plag, plagioclase; hb, hornblende; xls, crystals; MI, magmatic inclusion(s). Other abbreviations: MLV, Medicine Lake volcano; LBNM, Lava Beds National Monument; USGS, U.S. Geological Survey.

Detailed information about how MLV map units have been classified and interpreted and also how they are portrayed on map can be found in "Introduction to Description of Map Units" in report pamphlet (Report Pamphlet page 13).

Geologic units associated with the Geologic Sample Localities (LABEGSL) feature class/data layer are listed last.

Cenozoic Era

Quaternary Period

Holocene Epoch

Hp - Pumice
Hrgm - Rhyolite of Glass Mountain
Hrlg - Rhyolite of Little Glass Mountain
Hmpp - Basaltic andesite of Paint Pot Crater
Hmcf - Basaltic andesite of Callahan Flow
Hrh - Rhyolite of “Hoffman flows”
Habl - Andesite of Burnt Lava Flow
Hbbr - Basalt of Black Crater and Ross Chimneys
Hdpc - Dacite of pit craters
Hdm - Dacite of Medicine Lake Glass Flow

Holocene and Pleistocene Epochs

HPEl - Lake deposits

late Pleistocene Epoch

PEbv5 - Basalt of “vent 5”
PEbvc - Basalt of Valentine Cave
PEbgc - Basalt of Giant Crater
PEmgf - Basaltic andesite east of Grasshopper Flat
PEbtm - Basalt of tree molds

PEbdh - Basalt of Devils Homestead
PEbrf - Basalt of ribbon flows

Glacial till
PEt - Glacial till
PEbwc - Basalt of Water Caves
PEbup - Basalt under Paint Pot Crater flow
PEbec - Basalt east of Cinder Butte
PEbma - Basalt southeast of Mammoth Crater
PEmna - Basaltic andesite northeast of Aspen Crater
PEg - Gravel
PEbgd - Basalt of Gold Digger Pass
PEbc - Basalt of The Castles
PEms - Basaltic andesite of Stud Hill
PEbmc - Basalt of Mammoth Crater
PErmh - Rhyolite of Mount Hoffman
PEaib - Andesite of Indian Butte
PEbwh - Basalt west of Mount Hoffman
PEbuc - Basalt under Callahan Flow
PEbci - Basalt of Caldwell Ice Caves
PEmsm - Basaltic andesite south of Mammoth Crater
PEmts - Basaltic andesite of Three Sisters
PEasb - Andesite of Schonchin Butte
PEbpa - Basalt of The Panhandle
PEbeb - Basalt east of Big Sand Butte
PEbyb - Basalt of Yellowjacket Butte
PEbl - Lake Basalt
PEbt - Basalt of Tionesta
PEbls - Basalt of Little Sand Butte
PEdrs - Dacite of Red Shale Butte
PEanr - Andesite of north rim
PEbu - Basalt near Undertakers Camp
PEasm - Andesite south of Mammoth Crater
PEbsc - Basalt southwest of Cinder Butte
PErng - Rhyolite northwest of Glass Mountain
PEasr - Andesite of south rim
PEbnf - Basalt northeast of Fourmile Hill
PEbsl - Basalt south of Little Glass Mountain
PEaac - Andesite of Alcohol Crater
PEbac - Basalt of Aspen Crater
PEbrh - Basalt of Red Hill
PEawl - Andesite west and north of Little Glass Mountain
PEmnm - Basaltic andesite north of Medicine Lake
PEas - Andesite of south flank
PEbpw - Basalt near Pumice Stone Well
PEmel - Basaltic andesite east of Little Glass Mountain
PEmhi - Basaltic andesite of Hippo Butte
PEbts - Basalt of Three Sisters
PEmen - Basaltic andesite of Eagle Nest Butte
PEbnp - Basalt near Paint Pot Crater

late or middle Pleistocene Epoch
PEmfh - Basaltic andesite of Fourmile Hill

PEm1 - Basaltic andesite spatter vent west-northwest of Bat Butte
PEbdp - Basalt of Doe Peak

middle Pleistocene Epoch
PEawb - Andesite of Whitney Butte
PEama - Andesite southwest of Mammoth Crater
PEbnb - Basalt north of Burnt Lava Flow
PEbng - Basalt northeast of Glass Mountain
PEmuc - Basaltic andesite under Callahan Flow
PEa1 - Andesite cone west of Crescent Butte
PEaug - Andesite under Glass Mountain
PEm16 - Basaltic andesite cone north-northeast of Six Shooter Butte
PEawf - Andesite west of Fleener Chimneys
PEblh - Basalt of Little Mount Hoffman
PEaut - Andesite under Three Sisters
PEm2 - Basaltic andesite of Crescent Butte
PEbdb - Basalt of Damons Butte
PEbnw - Basalt north of Whitney Butte
PEmsc - Basaltic andesite of Semi Crater
PEanh - Andesite northeast of Mount Hoffman
PEbcb - Basalt of Canby Bay
PEb4 - Basalt of Caldwell Butte
PEmsp - Basaltic andesite east and northeast of Shotgun Peak
PEbei - Basalt east of Indian Butte
PEbwd - Basalt west of Doe Peak
PEadh - Andesite near Devils Homestead
PEb9 - Basalt cone north of Aspen Crater
PEmrs - Basaltic andesite of Red Shale Butte
PEmes - Basaltic andesite of East Sand Butte
PEaeg - Andesite east of Grasshopper Flat
PEbtw - Basalt of Twin Sister
PEds - Dacite of south flank
PEb5 - Basalt cone southeast of Mammoth Crater
PEbco - Basalt of Cougar Butte
PEay - Andesite under basalt of Yellowjacket Butte
PEmug - Basaltic andesite under Giant Crater lava field
PEm10 - Basaltic andesite cone southeast of Aspen Crater
PEb6 - Basalt cone at southeast end of Hidden Valley
PEbse - Basalt southwest of East Sand Butte
PEm9 - Basaltic andesite cone southwest of Aspen Crater
PEbpb - Basalt of Porcupine Butte and Timber Hill
PEm12 - Basaltic andesite cone southwest of Medicine Lake
PEa3 - Andesite of Island Butte
PEm14 - Basaltic andesite cone southeast of Paynes Springs
PEm7 - Basaltic andesite cone northeast of Aspen Crater
PEmdp - Basaltic andesite of Doe Peak
PEa5 - Andesite cone east of Fourmile Hill
PEm11 - Basaltic andesite cone west of Medicine Lake
PEbdc - Basalt of Deep Crater
PEm5 - Basaltic andesite cone north of Aspen Crater
PEacc - Andesite of Cinder Cone
PEmwg - Basaltic andesite west and north of Grasshopper Flat
PEmwc - Basaltic andesite in western Callahan Flow

PEbcu - Basalt of unnamed crater
PEm3 - Basaltic andesite of Big Sand Butte
PEmhm - Basaltic andesite adjacent to Harris Mountain
PEbgf - Basalt west of Canby Cross at Gillem Fault
PEmni - Basaltic andesite north of Indian Butte
PEbph - Basalt of Papoose Hill
PEasn - Andesite of Snag Hill
PEbnr - Basalt north of railroad
PEbwl - Basalt west of Lava Crack Spring
PEdta - Dacite tuff of Antelope Well
PEdls - Dacite east of Lost Spring
PEbst - Basalt southwest of Tickner Cave
PEmrc - Basaltic andesite of Red Cap Mountain
PEbsp - Basalt of Shotgun Peak
PEdec - Dacite east of Callahan Flow
PEmtc - Basaltic andesite near Tickner Cave
PEdeg - Dacite east of Glass Mountain
PEmbp - Basaltic andesite of Badger Peak
PEmc - Basaltic andesite south and southwest of Caldwell Butte
PEmnd - Basaltic andesite northeast of Doe Peak
PEa2 - Andesite of Red Butte
PEawh - Andesite west of Little Mount Hoffman
PEbeg - Basalt east of Glass Mountain
PEmph - Basaltic andesite of Powder Hill
PEasc - Andesite from cone at southeast edge of Callahan Flow
PEa4 - Andesite cone west of Cougar Butte
PEb12 - Basalt cone northeast of Doe Peak
PEa9 - Andesite cone southwest of Little Mount Hoffman
PEdac - Dacite in Aspen Crater
PEbsh - Basalt of Saddle Hills
PEmwd - Basaltic andesite west of Devils Homestead
PEa8 - Andesite cone south of Little Mount Hoffman
PEm19 - Basaltic andesite of Six Shooter Butte
PEa7 - Andesite cone west of Crater Glass Flow
PEb14 - Basalt cone east of Doe Peak
PEa6 - Andesite cone southwest of Fourmile Hill
PEb13 - Basalt cone east of Six Shooter Butte
PEb15 - Basalt cone south of High Hole Crater
PEanl - Andesite north of Little Glass Mountain
PEmsn - Basaltic andesite southwest of Snag Hill
PEm18 - Basaltic andesite cone south of Paint Pot Crater
PEbss - Basalt south of Squaw Peak
PEb11 - Basalt cone northeast of Six Shooter Butte
PEb17 - Basalt of Round Mountain
PEmtr - Basaltic andesite of “Tennant Road”
PEbh - Basalt of Hill 22
PEmlc - Basaltic andesite of Lava Crack Spring
PEb10 - Basalt cone southwest of Dock Well
PEb8 - Basalt cone east of Cinder Butte
PEbet - Basalt east of Timber Hill
PEmlh - Basaltic andesite of Little Mount Hoffman
PEb2 - Basalt cone at northeast edge of Sharp Mountain
PEdwm - Dacite west of Medicine Lake

PEb3 - Basalt cone at east edge of Sharp Mountain
PEbel - Basalt east of Lost Iron Well
PEawm - Andesite west of Medicine Lake
PEb1 - Basalt of Hardin Butte
PErcg - Rhyolite west of Crater Glass Flow
PEdsk - Dacite southwest of Kelley Pass
PEbp - Basalt of Prisoners Rock
PEdike - Dike
PEmnl - Basaltic andesite north of Lookout Butte
PEb7 - Basalt cone southwest of Bonita Butte
PEarr - Andesite of old railroad
PEm17 - Basaltic andesite cone northeast of Cinder Cone
PEmj - Basaltic andesite of Juniper Butte
PEb16 - Basalt of Snell Butte
PEbea - Basalt east of Antelope Well
PEmrr - Basaltic andesite of railroad
PEm4 - Basaltic andesite cone southwest of Cinder Butte
PEm6 - Basaltic andesite cone northwest of Lookout Butte
PEatm - Andesite of Typhoon Mesa
PEm8 - Basaltic andesite cone northwest of Fourmile Hill
PEm15 - Basaltic andesite cone south of Little Glass Mountain
PEmtl - Basaltic andesite of Tamarack Lake
PEafr - Andesite of Fisk Ridge
PEmws - Basaltic andesite west of Squaw Peak
PEm13 - Basaltic andesite southwest of Kephart
PEmrl - Basaltic andesite of road to Lost Spring
PEael - Andesite east of Lost Spring
PEmwr - Basaltic andesite west of Red Cap Mountain
PEaes - Andesite east of Six Shooter Pass
PEmsr - Basaltic andesite southwest of Red Cap Mountain
PEmtf - Basaltic andesite of Tamarack Flat
PErec - Rhyolite east of Callahan Flow
PErsl - Rhyolite south of Little Sand Butte
PEbsr - Basalt southwest of Red Cap Mountain
PErse - Rhyolite at southeast edge of Callahan Flow
PErwc - Rhyolite west of Callahan Flow
PEaet - Andesite east of Typhoon Mesa
PErgf - Rhyolite of Grasshopper Flat
PEmnp - Basaltic andesite northwest of Paint Pot Crater
PErcb - Rhyolite near Cougar Butte
PEbug - Basalt under Giant Crater lava field
PEbhp - Basalt of Hovey Point
PEreg - Rhyolite east of Glass Mountain
PEbhi - Basalt of Hambone Island
PEobw - Older basalt of Garner Mountain
PEobd - Older basalt of Dry Lake
PEopt - Older palagonite tuff
PEomf - Older basaltic andesite of Fisk Ridge
PEoag - Older andesite of Garner Mountain
PEomb - Older basaltic andesite of Black Mountain

middle or early Pleistocene Epoch
PEoml - Older basaltic andesite of Lost Iron Well

PEobc - Older basalt of Casuse Mountain
PEog - Older gravel deposits
PEol - Older lake sediments
PEoap - Older andesite of Pumice Stone Mountain
PEob - Older basalt

early Pleistocene Epoch
PEobu - Older basalt under Black Mountain
PEorr - Older rhyolite of Red Cap Mountain
PEord - Older rhyolite near Dock Well
PEobp - Older basalt on west side of Gillem Fault
PEods - Older dacite of Squaw Peak
PEotb - Older tuff of Box Canyon
PEom - Older basaltic andesite of Bonita Butte

Pliocene Epoch
PLomt - Older basaltic andesite of Timber Mountain
PLotg - Older tuff of Gillem Bluff
PLomg - Older basaltic andesite of Gillem Bluff
PLobg - Older basalt of Gillem Bluff
PLomw - Older basaltic andesite in western Lava Beds National Monument
PLodh - Older dacite of Harris Mountain

Units found only in the Geologic Sample Localities (LABEGSL) Feature Class

Quaternary Period
Qagm - Andesite near Garner Mountain
Qrdh_57-13 - Rhyolite at 1459' in drill hole 57-13
Qrdh_68-16 - Rhyolite at 1673' in drill hole 68-16
Qbpr - Basalt of Plum Ridge
Qbh5160 - Basalt of Hill 5160
Qrbc - Rhyolite tuff of Box Canyon
Qblpb - Basalt of Lone Pine Butte
Qbcbl - Basalt of Chalk Bank Landing
Qdclr - Basalt south of Clear Lake Reservoir
Qbkb - Basalt of Knobcone Butte
Qadhm - Andesite N.W. of Double Head Mountain
Qdgb - Dacite tuff of Gillem Bluff

Tertiary Period
Tmhjb - Basaltic andesite of Harvey Jones Butte
Tmwf - Basaltic andesite dike near Winema Farms
Tbhr - Basalt of High Rim
Tdcl - Dacite of the Clear Lake Hills

Unit and Ages Unknown
unk - Unit unknown

Map Unit Descriptions

Descriptions of all geologic map units, generally listed from youngest to oldest, are presented below.

Hp - Pumice (Holocene)

Mapped only where thick deposits of pumice obscure underlying units and contacts. Consists of pumice deposited by air fall from eruptions at Little Glass Mountain and Glass Mountain. Isopach maps and detailed descriptions of these pumice deposits are included in Fisher (1964) and Heiken (1978). Little Glass Mountain tephra deposit is strongly elongated southwest-northeast, whereas Glass Mountain tephra is found mainly north and northeast of lava flows and domes emplaced after tephra. Deposits are depicted on map in following areas: adjacent to Glass Mountain, Little Glass Mountain, and Crater Glass Flow; in basin that contains Pumice Stone Well; in two low areas west of Squaw Peak; and in two low areas within caldera, notably at Arnica Sink. Sectors D, E, F, J, K, L. *GRI Source Map ID 7411.* (*Lava Beds NM*).

Hrgm - Rhyolite of Glass Mountain (Holocene)

Aphyric to variably porphyritic, compositionally zoned rhyolite to andesite, but dominantly rhyolitic (61.3–74.6% SiO2). Initial tephra eruption formed deposits as thick as 10 m that were subsequently exposed by pumice mining. Flows and multiple domes were erupted from about 15 vents along northwest-trending fissure high on east rim of MLV. Glass Mountain was known originally as “Big Glass Mountain” (Powers, 1932); it was studied and mapped by C.A. Anderson (1933), by Eichelberger (1975, 1981), and by Donnelly-Nolan and Grove (2008). Lavas that have highest silica contents are aphyric. Phenocrysts in rhyolitic (70–73% SiO2) lava: typically, 1–2% 1 mm plag; rare =1 mm opx; ±MI and their debris. Phenocrysts in dacitic (<70% SiO2) lavas and in andesitic scoria (incorporated within zones of disrupted initial pumice cone deposits): typically, 1–3% 1–3 mm plag; 1% 1 mm opx. Rare partially melted granitic inclusions have been found in two small domes. Also present in main flow and in many domes are MI (<1–70 cm) and 5–10% of disaggregated MI material (plag+ol+cpx, plag>ol>cpx), amount of such material increasing as silica content of unit decreases; see Grove and others (1997), as well as Grove and Donnelly-Nolan (1986), for additional chemical analyses. Flow and domes cover approximately 14.0 km2. Unit has estimated volume of 1 km3, including tephra, which is estimated to constitute 10 percent of total volume (Heiken, 1978). Maximum thickness of lava flows varies from approx 30 m for dacite lobes to approx 100 m for last-erupted rhyolite lobe. Three areas of surficial unit p immediately north and south of unit consist dominantly of tephra of this unit. Overlies all adjacent units and is youngest unit at MLV. Calibrated age of 890 yr B.P. (Donnelly-Nolan and others, 2007; Nathenson and others, 2007) is based on radiocarbon ages published in Donnelly-Nolan and others (1990) and Champion and others (2005). Sectors C, D, E, F. *GRI Source Map ID 7411.* (*Lava Beds NM*).

Hrlg - Rhyolite of Little Glass Mountain (Holocene)

Poorly porphyritic rhyolite (72.6–74.2% SiO2; avg of 9 = 73.9%) consisting of tephra and multiple lava flows and domes that were erupted from more than a dozen vents along two en echelon fissures having approx N. 30° E. trends. Estimated area covered is 6.3 km2; estimated volume is approx 0.4 km3. Unit contains obsidian and variably vesicular pumice. No stony interior rhyolite is exposed. Location is west and northwest of caldera. Extent of unit from southwest edge of largest and southwestern most lava flow to northeast end of eruptive fissure is approx 10 km. Northeastern domes include Crater Glass Flow and additional domes farther along northeast trend. Emplacement of Little Glass Mountain was described by Fink (1983), as were its surficial features. Eruption was accompanied by formation of open ground

cracks, as described by Fink and Pollard (1983). Tephra plume that extended both northeast and southwest preceded eruption of lava flows and domes (Fisher, 1964; Heiken, 1978). Phenocrysts: approx 1% 1–2 mm plag, mostly 1 mm; <<1% 1 mm opx. Unit also contains <1% inclusions: lithic fragments that are dominantly granite; MI to 0.8 m in diameter of basaltic andesite to andesite composition; and cumulate inclusions (see Mertzman and Williams, 1981; Grove and Donnelly-Nolan, 1986; Brophy and others, 1996). Overlies all adjacent units: awh, mbp, aeg, bnp, bpw, awl, bsl, and anr, as well as surficial unit p, which in this area consists dominantly of tephra from initial explosive eruption that resulted in emplacement of lava flow. Calibrated radiocarbon age is 940 yr B.P. (Donnelly-Nolan and others, 2007; Nathenson and others, 2007). Sectors C, D, E, F. *GRI Source Map ID 7411.* (*Lava Beds NM*).

Hmpp - Basaltic andesite of Paint Pot Crater (Holocene)

Moderately porphyritic basaltic andesite (52.9–53.2% SiO2; avg of 4 = 53.1%) that was erupted in late Holocene time from cinder cone and multiple spatter vents aligned N. 40° E. Length of flow is less than 4 km. Area covered is approx 2.7 km2; volume is approx 0.04 km3. At and near vents, unit has significant mantle of white pumice (not mapped) from eruption of nearby Little Glass Mountain. Distal end of flow is nearly bare of pumice and trees and is extremely rugged, displaying numerous 5- to 10-m-high spines and mounds of lava and spatter. Phenocrysts, approx 5%: 1–2 mm plag+ol, plag>ol. Partially melted granitic inclusions and MI as large as 3 cm are present. Overlies all adjacent units (oap, rgf, m18, dta, mwg, mug, bnp, awl, bsl, bup). Calibrated age of 1,110 yr B.P. is based on estimate derived from stratigraphic relation of its tephra (Donnelly-Nolan and others, 1990) to radiocarbon-dated tephras (its tephra overlies tephra of unit mcf and underlies tephra of unit rlg) and on paleomagnetic constraints (Donnelly-Nolan and others, 2007; Nathenson and others, 2007). Sectors C, D. *GRI Source Map ID 7411.* (*Lava Beds NM*).

Hmcf - Basaltic andesite of Callahan Flow (Holocene)

Compositionally variable (51.8–57.8% SiO2; avg of 40 = 55.1%) and variably porphyritic, blocky lava flow consisting of basalt, basaltic andesite, and andesite (Mertzman, 1977a; Kinzler and others, 2000). Lava flows were erupted from Cinder Butte and adjacent smaller vents 6.5 km from northern terminus of flow. Estimated area covered is 23.7 km2; volume is approx 0.33 km3. Phenocrysts: basalt facies is nearly aphyric, <<1% 1–2 mm plag±ol; andesite facies, 2–5% 1–3 mm plag, a few 1 mm opx xls, rare 1 mm ol. Cinder Butte contains partially melted silicic inclusions; one MI was found in flow (Kinzler and others, 2000). Unit overlies all adjacent units and is one of youngest eruptive units at MLV; some pumice (not mapped) from Little Glass Mountain (unit rlg) and probably from Glass Mountain (unit rgm) is found on flow. Calibrated age of 1,120 yr B.P. (Donnelly-Nolan and others, 2007; Nathenson and others, 2007) is based on three radiocarbon ages (Donnelly-Nolan and others, 1990). Previously designated as “unit ba” of Donnelly-Nolan and Champion (1987). Sectors G, H, I. *GRI Source Map ID 7411.* (*Lava Beds NM*).

Hrh - Rhyolite of “Hoffman flows” (Holocene)

Porphyritic rhyolite and dacite (68.4–72.4% SiO2; avg of 7 = 70.9%) of two young, steep-sided flows that were erupted from N. 25° W.–trending, en echelon alignments of nearly a dozen vents, including aligned explosion craters located on east edge of the rhyolite of Mount Hoffman (unit rmh). Lava was erupted near caldera rim, flowing both inward and outward. Estimated area is 5.5 km2; estimated volume is 0.2 km3. Unit is significantly mantled near Glass Mountain by pumice of Glass Mountain (unit rgm) eruption and by vegetation that has grown on pumice. Farther away, at west end of unit, flow has very youthful appearance. Tephra deposit ascribed to this unit has been exposed by quarrying in surficial unit p north of Glass Mountain. Rock contains abundant MI (commonly disc shaped), most of which are fine grained,

but some are cumulate in texture; rock also contains scattered xenoliths. MI are so common, and many MI are so small, that it is not possible to remove them all, thus resulting in lowered silica content when host rock is analyzed by whole-rock methods. Phenocrysts: 5–10% 1–2 mm plag; =1% 1 mm opx, commonly in vitric groundmass. Overlies all adjacent units (anh, bac, aac, anr, drs, bl, rmh) except unit rgm and surficial unit p; underlies tephra of units mcf and rlg. Calibrated age of 1,170 yr B.P is based on radiocarbon ages not previously ascribed to this unit (Donnelly-Nolan and others, 2007; Nathenson and others, 2007). Sectors J, K, L. *GRI Source Map ID 7411.* (*Lava Beds NM*).

Habl - Andesite of Burnt Lava Flow (Holocene)

Sparsely porphyritic andesite (56.4–57.9% SiO2; avg of 5 = 57.3%) flow, mostly aa, that was erupted from High Hole Crater cinder cone and from spatter vents to north. Covers approx 34.3 km2 and has volume of approx 0.5 km3. Compositional variation is present within lava flow, but no attempt has been made to map areal distribution of compositions because of limited petrographic variability visible in hand specimens; however, examination of aerial photographs together with analyses given for 20 sample localities in Grove and others (1988) indicates that earlier erupted lava is more mafic than later erupted lava. Unit contains common fine-grained MI that range in size from microscopic to 20 cm across and in composition from 47.5 to 51.4% SiO2; partially melted granitic inclusions also are present (Grove and others, 1988). Early geologic description of lava flow was published by Finch (1933). Phenocrysts: 1–2% 1–3 mm plag; a few 1 mm ol; sparse plag+ol clots. Overlies all adjacent units (b15, bsp, bdc, ay, msp, asr, bu, bl, byb, ms, brf); underlies only rhyolitic pumice (not mapped) from Little Glass Mountain (unit rlg) (and possibly from Glass Mountain, unit rgm). Because of youthful appearance of this rugged, mostly unvegetated lava flow, unit originally was thought to have been erupted as recently as 300 years ago (Finch, 1933). Calibrated age of 2,950 yr B.P. (Donnelly-Nolan and others, 2007; Nathenson and others, 2007) is based on two radiocarbon ages (Donnelly-Nolan and others, 1990). Sectors A, M. *GRI Source Map ID 7411.* (*Lava Beds NM*).

Hbbr - Basalt of Black Crater and Ross Chimneys (Holocene)

Very porphyritic basalt (48.3–50.6% SiO2; avg of 21 = 49.5%), found in two small areas in northern part of LBNM. Covers approx 0.45 km2, having total volume of approx 0.001 km3. Was erupted from numerous north-northeast-trending spatter cones that form en echelon linear arrays. Vents for topographically lower, more northerly patch of lava, known as Ross Chimneys, produced basalt that ranges in composition from 48.3 to 49.6% SiO2. Vents for upper patch, known as Black Crater, and its associated spatter vents erupted lava that ranges in composition from 49.2 to 50.6% SiO2. In general, silica content decreases with decreasing elevation. Lava from topographically higher Black Crater vents overlies lava from topographically lower Black Crater vents, suggesting that higher silica lava erupted after lower silica lava. Open ground cracks, which are on same trend and have same orientation as vents, extend north toward boundary of LBNM and may have opened during this eruption. Phenocrysts, 20–25%: mostly 2–4 mm plag, some plag =1 cm; includes 2–4% 1–2 mm ol. Overlies all adjacent units (bmc, men, msc). Calibrated radiocarbon age is 3,080 yr B.P. (Donnelly-Nolan and others, 2007; Nathenson and others, 2007). Sector I. *GRI Source Map ID 7411.* (*Lava Beds NM*).

Hdpc - Dacite of pit craters (Holocene)

Nearly aphyric, low-silica dacite (two analyses, 63.4% SiO2) that was erupted as tephra and spatter from numerous pit craters aligned approx N. 30–40° E. One of largest craters, located just northwest of junction of major roads approx 1 km northeast of Undertakers Camp, displays good exposures of welded-spatter “flows” of this unit on northwest wall of crater. Most of unit as shown on map consists of

near-vent vesicular blocks as much as 1 m across; farther from vent, tephra of unit is mapped where it obscures underlying units. Tephra of this unit is more extensive than is shown in 1 km by 3 km mapped area and is noticeable on Red Shale Butte and Lyons Peak. Approximate area and volume of unit are 2.4 km2 and 0.02 km3, respectively. Northeast-trending cracks beyond northeastern most extent of unit apparently opened during eruption but did not erupt magma. Phenocrysts: <<1% 1 mm plag; rare small pyx xls in groundmass. Angular lithic fragments of underlying lava flows also are present, including car-sized blocks of Lake Basalt (bl) that were thrown out of crater at northeast end of map unit. Overlies all adjacent units (msp, bu, bl, surficial unit t). Calibrated age of 5,040 yr B.P. (Donnelly-Nolan and others, 2007; Nathenson and others, 2007) is based on two radiocarbon ages (Donnelly-Nolan and others, 1990). Sectors L, M. *GRI Source Map ID 7411.* (*Lava Beds NM*).

Hdm - Dacite of Medicine Lake Glass Flow (Holocene)

Porphyritic dacite (68.2–68.8% SiO2; avg of 3 = 68.5%) of young, rugged and unmodified, pancake-like flow that covers approx 2.4 km2 of caldera floor between Medicine Lake and north caldera rim. Volume is approx 0.08 km3. Also known as “Medicine flow” (Powers, 1932), “Medicine dacite” (C.A. Anderson, 1941), and “Medicine dacite flow” (Donnelly-Nolan and others, 1990). Entire flow is edged by unstable talus slopes 25–40 m high of mostly glassy blocks. Two vent areas are defined by abundance of vertical spines of lava and by enclosing concentric or aligned pressure ridges; vents are aligned N. 45° W. Flow contains variety of sparsely distributed inclusions: granitic and mafic plutonic xenoliths, cumulate gabbroic inclusions, and fine-grained MI (one contains 60.4% SiO2; Grove and Donnelly-Nolan, 1986). Phenocrysts, host lava: 5–7% 1–3 mm plag; approx 1% 1–2 mm opx. Sparse microscopic hb xls (rare at MLV) are present in groundmass. Overlies units anr and bl, as well as surficial unit l (in this area, lake sediments deposited by former high stand of Medicine Lake). Calibrated age of 5,140 yr B.P. is based on estimate derived from sedimentation rate and stratigraphy in Medicine Lake sediments (Donnelly-Nolan and others, 2007; Nathenson and others, 2007). Sectors G, H, I, J. *GRI Source Map ID 7411.* (*Lava Beds NM*).

HPEl - Lake deposits (Holocene and Pleistocene)

Fine-grained, water-laid sediments in low, flat areas scattered around MLV. All sectors. *GRI Source Map ID 7411.* (*Lava Beds NM*).

PEbv5 - Basalt of “vent 5” (late Pleistocene)

Sparsely porphyritic basalt (two analyses, 52.7% SiO2) flow and spatter vents that may represent late tap of magma system responsible for Giant Crater lava field (unit bgc). Spatter vents are aligned N. 20–25° W., but they, in turn, are on trend (N. 55–60° E) with four vents of Giant Crater system (thus, “vent 5”). Very small flow covers about 0.12 km2; estimated volume is 0.0002 km3. Phenocrysts, approx 5%: mostly 1–4 mm plag; 1 mm ol; plag>>ol; numerous plag+ol clots =1 cm. Overlies units mug and bgc. Previously published radiocarbon age (Donnelly-Nolan and others, 1990), considered too young, has been calibrated, on basis of paleomagnetic direction and comparison with other dated units, to be 12,270 yr B.P. (Donnelly-Nolan and others, 2007; Nathenson and others, 2007). Sector B. *GRI Source Map ID 7411.* (*Lava Beds NM*).

PEbvc - Basalt of Valentine Cave (late Pleistocene)

Sparsely porphyritic basalt and basaltic andesite (52.9, 52.9, 53.4% SiO2; avg of 3 = 53.0%) of early postglacial flow that was erupted from northwest-trending linear array of spatter cones at 5,400 to 5,600 ft (1,646 to 1,707 m) elevation on north flank of MLV, just south of LBNM. Unit is estimated to cover 19.9 km2 and to have volume of 0.2 km3. Nearly all of flow was erupted from vents known as Tickner Chimneys, but separated from these are additional vents uphill to southeast that produced very small lava flow. Main flow hosts several lava-tube caves, including much-visited Valentine Cave in LBNM. It is unusual at MLV for flow that has such a high silica content to generate lava tubes, but the explanation may relate to its high iron and titanium contents, apparently resulting in lowered viscosity. Phenocrysts, variable: more abundant in vent lavas, 2–3% 1 mm plag, 1% 1–4 mm plag+ol clots; less abundant in downstream lavas, 1% plag+ol clots. Overlies all adjacent units: mc, mtc, bst, m3, b4, bng, bci, aib, bmc, and mna, as well as surficial unit g, which in this area is glacial-outwash gravel formerly exposed in quarry east of paved park road, about 0.5 km east of Caldwell Butte; white pebbles in glacial-outwash gravel are pumice that is compositionally identical to the rhyolite of Mount Hoffman (rmh). Previously published radiocarbon age (Donnelly-Nolan and others, 1990), considered too young, has been calibrated, on basis of paleomagnetic direction and comparison with other dated units, to be 12,260 yr B.P. (Donnelly-Nolan and others, 2007; Nathenson and others, 2007). Sectors I, J, K. *GRI Source Map ID 7411.* (*Lava Beds NM*).

PEbgc - Basalt of Giant Crater (late Pleistocene)

Variably porphyritic and chemically variable, postglacial basaltic (47.7–53.2% SiO2; avg of 84 USGS analyses = 49.5%) lava field, extending 45 km south from numerous vents on south flank of MLV between 5,000 ft (1,524 m) and 6,000 ft (1,829 m) elevation. Many vents are aligned north-south; others, N. 55° E. (see Donnelly-Nolan and others, 1991, for vent locations and additional description). Area covered by unit is about 198 km2; volume is about 4.35 km3. Includes isolated spatter cones found within Double Hole Crater lobe. Six chemical subgroups within lava field have been mapped and described by Donnelly-Nolan and others (1991); their petrographic description (see p. 21,844) is quoted here:

> "Group 1 lavas are the most porphyritic with about 5% of phenocrysts of plagioclase and olivine and an occasional 1–3 mm quartz grain. Plagioclase crystals are as long as 6 cm. Group 2 and 3 lavas contain decreasing amounts of phenocrysts and the plagioclase megacrysts are typically smaller, usually 1–2 cm across in group 3 lavas. The distinctions between groups 1 and 2 and between groups 2 and 3 are difficult to make in the field. Group 4 lavas, however, are distinctive. They are typically massive and aphyric with rare plagioclase megacrysts to 1 cm across. Group 5 lavas are aphyric but diktytaxitic and can be distinguished fairly readily from group 4 lavas but not from group 6. All groups include both aa and pahoehoe lavas."

More detailed petrographic descriptions are given in Baker and others (1991; see p. 21,820). As depicted on this map, unit includes very small "spatter vents in Double Hole Crater flow" unit described in Donnelly-Nolan and others (1990, 1991). Unit also contains melted granitic inclusions and mafic cumulate inclusions (Baker and others, 1991). Underlies unit bv5; overlies all other adjacent units. Unit is displaced as much as 10 m down to west by Mayfield Fault. Calibrated age of 12,430 yr B.P. (Donnelly-Nolan and others, 2007; Nathenson and others, 2007) is based on two radiocarbon ages (Donnelly-Nolan and others, 1990). Sectors A, B. *GRI Source Map ID 7411.* (*Lava Beds NM*).

PEmgf - Basaltic andesite east of Grasshopper Flat (late Pleistocene)

Sparsely porphyritic basaltic andesite (54.3% SiO2) of north-south-trending spatter rampart and very small lava flows (area, approx 0.02 km2; estimated volume, less than 0.0001 km3). Phenocrysts: 1–2% 1 mm plag; some 3–4 mm clots of plag+ol+cpx. Was erupted through and onto unit aeg (only unit with which it is in contact). Previously published radiocarbon ages (Donnelly-Nolan and others, 1990), considered too young, have been calibrated, on basis of paleomagnetic direction and comparison with other dated units, to be 12,490 yr B.P. (Donnelly-Nolan and others, 2007; Nathenson and others, 2007). Sector C. *GRI Source Map ID 7411.* (*Lava Beds NM*).

PEbtm - Basalt of tree molds (late Pleistocene)

Porphyritic basalt (51.9% SiO2) that was erupted from N. 10° E.–trending spatter cones south of Callahan Flow (unit mcf) near east base of Fourmile Hill. Small thin flow surrounded several trees just downstream from vents, preserving tree molds. Total area covered by unit is approx 0.05 km2; estimated volume is 0.0001 km3.Phenocrysts: 5% plag, mostly 1–2 mm, some =2 cm; 1% 1 mm ol; scattered plag+ol clots. Overlies unit anr. Previously published radiocarbon age (Donnelly-Nolan and others, 1990), considered too young, has been calibrated, on basis of paleomagnetic direction and comparison with other dated units, to be 12,330 yr B.P. (Donnelly-Nolan and others, 2007; Nathenson and others, 2007). Sector G. *GRI Source Map ID 7411.* (*Lava Beds NM*).

PEbdh - Basalt of Devils Homestead (late Pleistocene)

Young, sparsely porphyritic basalt (51.3, 51.4% SiO2) flow and spatter vents known as Fleener Chimneys. Aa flow makes up rugged Devils Homestead in LBNM, although much of lava near vent is pahoehoe. Area covered by unit is approx 4.1 km2; volume is approx 0.04 km3. Vents, located at bend along predominantly north-south-trending Gillem Fault, are aligned approx N. 20–25° E. Phenocrysts: 1–2% plag, mostly 1–3 mm, some =1 cm long. Overlies all adjacent units (adh, bcb, msc, awf, men, bmc). Age is postglacial, on basis of paleomagnetic data and morphologic comparison with other lava flows (Donnelly-Nolan and others, 1990). Calibrated age of 12,320 yr B.P. is based on estimate derived from comparison of paleomagnetic direction with other dated units (Donnelly-Nolan and others, 2007; Nathenson and others, 2007). Sectors H, I. *GRI Source Map ID 7411.* (*Lava Beds NM*).

PEbrf - Basalt of ribbon flows (late Pleistocene)

Sparsely to moderately porphyritic basalt (49.0–50.5% SiO2; avg of 5 = 49.9%) forming narrow lava flows that occupy channels presumably cut by glacial meltwater. Was erupted from numerous spatter vents approx 3 km north of Burnt Lava Flow (unit abl). Vents, situated at north end of unit, are aligned slightly east of north to slightly west of north. Lava flows extend more than 10 km south-southeast from vent area and, for much of their length, are buried by Burnt Lava Flow; unit also crops out at southeast edge of Burnt Lava Flow. Estimated area and volume are 8 km2 and 0.02 km3. Phenocrysts: 1–5% plag+ol, typically 1–2 mm; some plag =4 mm; plag>ol; plag+ol also in clots =3 cm across. MI were seen but were too small to collect for chemical analysis. Overlies all adjacent units (msp, bnb, bl, byb) except Burnt Lava Flow (abl). Previously published radiocarbon age (Donnelly-Nolan and others, 1990), considered too young, has been calibrated, on basis of estimate derived from comparison with paleomagnetic data of dated flows of similar age, to be 12,480 yr B.P. (Donnelly-Nolan and others, 2007; Nathenson and others, 2007). *Sector M. GRI Source Map ID 7411.* (*Lava Beds NM*).

PEt - Glacial till (late Pleistocene)

Includes boulders, cobbles, gravel, and interstitial finer grained material deposited directly by glaciers that formerly existed on top of MLV. Only better defined and more extensive deposits are mapped. Other till is present only in small patches or is poorly exposed. Because of poor exposure and limited extent of deposits, no attempt has been made to separate glacial deposits of different ages (see fig. 7, on sh. 2, for approximate distributions). Several mapped areas are younger than volcanic units on caldera rim, including areas on unit anr, areas on and near Medicine Mountain on unit asr, and one area at edge of Red Shale Butte that is younger than the Lake Basalt (bl) and thus is less than about 89 ka in age. Mapped area on north side of Mount Hoffman is deposited in cirque cut by latest Pleistocene glaciers and is younger than 28±5 ka, which is age of the rhyolite of Mount Hoffman (rmh); cobbles of unit rmh are present in till on south side of caldera. Till at Little Medicine Lake is mapped as younger than unit anr. Largest area of till, about 3 km south-southeast of Medicine Lake, includes several low morainal ridges and thin scattering of till over lava of unit asr. Sectors A, B, C, E, F, J, L, M. *GRI Source Map ID 7411.* (*Lava Beds NM*).

PEbwc - Basalt of Water Caves (late Pleistocene)

Poorly porphyritic basalt and basaltic andesite (49.9–53.7% SiO2; avg of 8 = 52.4%) that was erupted from two large spatter vents aligned N. 20° W. on south flank of MLV. Tube-fed flows extend at least 17 km south-southeast from vent area. On Hambone Island, excavation revealed that glacial-outwash gravel overlies unit, much of which has aa morphology and very youthful appearance. Phenocrysts, <1%: =1 mm ol+plag, ol>plag; rare 2 mm plag. Overlies units bhi, bug, bpb, asn, and byb; underlies unit bgc. See Champion and Donnelly-Nolan (1994) for additional discussion of unit age. Sectors A, B. *GRI Source Map ID 7411.* (*Lava Beds NM*).

PEbup - Basalt under Paint Pot Crater flow (late Pleistocene)

Plagioclase-phyric, moderately porphyritic basalt (49.0% SiO2) flow and N. 40° E.–aligned spatter cones that cover very small area. Very youthful in appearance and may be postglacial in age, but no material was found for radiocarbon dating. Unit is petrographically distinctive at MLV for its abundance of large (=1 cm) plag phenocrysts, approx 3% total; abundant small (=1 mm) plag+ol, plag>ol. Overlies units mwg, bnp, and bsl; underlies unit mpp. Sector C. *GRI Source Map ID 7411.* (*Lava Beds NM*).

PEbec - Basalt east of Cinder Butte (late Pleistocene)

Sparsely porphyritic basalt (51.6% SiO2) that was erupted from quarried spatter vents located east of Cinder Butte. Overall trend of two closely spaced north-south-trending vents and a third, more northern vent is approx N. 30° E. Morphology is youthful; lava channels and small lava tubes are present. Phenocrysts: 1% 1–3 mm plag; sparse 1 mm ol xls; rare =4 mm plag+ol clots. Overlies units rse, rec, dec, and mnm; also overlies northeast-trending fault; underlies unit mcf. May have been erupted after latest glaciation. Sector H. *GRI Source Map ID 7411.* (*Lava Beds NM*).

PEbma - Basalt southeast of Mammoth Crater (late Pleistocene)

Poorly porphyritic, diktytaxitic basalt (48.6% SiO2) of small flow that was erupted from spatter vent on south side of cinder cone (unit b5) just southeast of Mammoth Crater. Phenocrysts: <1% 1 mm plag+ol.

Overlies unit bmc and isolated cinder cone units b5 and b6. Sector I. *GRI Source Map ID 7411.* (*Lava Beds NM*).

PEmna - Basaltic andesite northeast of Aspen Crater (late Pleistocene)

Porphyritic basaltic andesite (53.1–54.1% SiO2; avg of 3 = 53.7%) that was erupted from north-northeast-trending alignment of spatter and cinder cones. Lava flow has youthful appearance. In addition, lava flow failed to cover flat area where unconsolidated glacial-outwash gravel (later quarried) was present in late-glacial, or immediately postglacial, time, and lava flow was diverted around wet area. All these factors suggest late Pleistocene age. Amount of soil that mantles unit near vent, as well as breakdown of lava tubes in unit, is greater than what is seen in other early postglacial flows. Phenocrysts, 5–10%: 1–4 mm plag; 1–2 mm ol; plag>ol; plag+ol clots =1 cm. Underlies unit bvc; overlies all other adjacent units (mtc, bst, m5, m7, b9, bac, asm, aib, surficial unit g). Sector J. *GRI Source Map ID 7411.* (*Lava Beds NM*).

PEg - Gravel (Pleistocene)

Includes boulders as much as a meter across, but dominant size range consists of pebbles to small cobbles; deposited in widely scattered areas distributed on middle to lower flanks of MLV. Consists primarily of glacial-outwash gravel associated with deglaciation, as well as gravels deposited by flood that was generated when the dacite tuff of Antelope Well (dta) erupted onto summit ice cap (Donnelly-Nolan and Nolan, 1986) about 180,000 years ago (age of unit dta). All sectors except D, H, K. *GRI Source Map ID 7411.* (*Lava Beds NM*).

PEbgd - Basalt of Gold Digger Pass (late Pleistocene)

Poorly porphyritic basalt (49.6–50.7% SiO2; avg of 8 = 50.4%) on lower north flank of MLV. Has youthful, well-preserved morphology similar to the (underlying) basalt of Mammoth Crater (bmc). Exposed flow length approx 11 km. Broken by both northwest-trending and northeast-trending faults. Vent area presumably buried by Callahan Flow (unit mcf) to south. Phenocrysts: approx 1% 1 mm ol; sparse 1 mm plag xls. Overlies units om, ob, opt, dta, awf, awb, buc, and bmc; underlies unit mcf. Sectors G, H. *GRI Source Map ID 7411.* (*Lava Beds NM*).

PEbc - Basalt of The Castles (late Pleistocene)

Aphyric, diktytaxitic basalt (48.6% SiO2) fed from many tens of spatter cones, including The Castles near west base of Schonchin Butte. One major vent is lava lake west of Semi Crater. Most vents are aligned north-northeast, but some are oriented north-northwest to northwest. Most of unit is located west of Schonchin Flow (unit asb), but one area is located at its northeast edge. Unit contains small lava tubes and lava-tube caves. Overlies all adjacent units (b1, bcb, msc, asb, bmc). Degree of spatter-vent breakdown indicates that unit is not Holocene. Sector I. *GRI Source Map ID 7411.* (*Lava Beds NM*).

PEms - Basaltic andesite of Stud Hill (late Pleistocene)

Moderately porphyritic basaltic andesite (56.8% SiO2) cone and youthful-looking block-lava flow, located west of Burnt Lava Flow (unit abl). Phenocrysts, approx 5%: mostly 1–3 mm plag; includes approx 1% 1

mm ol. Overlies units bdc, ay, as, asr, and byb; underlies units bgc and abl. Sector A. *GRI Source Map ID 7411.* (*Lava Beds NM*).

PEbmc - Basalt of Mammoth Crater (late Pleistocene)

Compositionally variable (48.4–55.9% SiO2; avg of 45 = 52.3%) basalt and basaltic andesite. Unit is dominantly basalt and consists of widespread lava flows, mostly fed by lava tubes as far as 25 km from vent area. Vents are in southern part of lava field and include Mammoth Crater, Modoc Crater, and Bat Butte, as well as a spatter rampart on north side of Bearpaw Butte and other north- and northwest-aligned pit craters and spatter vents. At its northeast edge, unit entered ancient Tule Lake and formed pillow lavas and littoral cones of Hospital Rock. Numerous north-northwest- to north-northeast-trending faults, including open ground cracks, cut unit. Phenocrysts: most mafic samples (48.4% SiO2) are essentially aphyric, having rare 1 mm ol±plag; most silicic samples, 1–2% 1–3 mm plag. Unit can sometimes be distinguished by reddish patina. Overlies numerous units, including dated units dta and asb; underlies units bgd, bc, bma, bdh, bvc, bbr, and mcf, as well as surficial unit g. 40Ar/39Ar age is 36 ±16 ka (table 1). See Donnelly-Nolan and Champion (1987) for more detailed description of unit. Sectors G, H, I, J, K. *GRI Source Map ID 7411.* (*Lava Beds NM*).

PErmh - Rhyolite of Mount Hoffman (late Pleistocene)

Porphyritic rhyolite (71.7–71.9% SiO2; avg of 3 = 71.8%) lava flow that was erupted from vent marked by dome of Mount Hoffman, highest point on volcano at 7,913 ft (2,412 m). Lava flow margins are as high as 100 m. Perlitic texture present in glassy facies may reflect ice contact; scallop out of north-northeast side of flow is glacial cirque. Glacial debris of this unit is present as rounded pebbles 7 km to north on floor of Hidden Valley, just east of Mammoth Crater; rounded pebbles of this unit also are present in former gravel quarry (now filled) east of Caldwell Butte; rounded cobbles of this unit also are present in till of surficial unit t, south of caldera between Shotgun Peak and south caldera rim. Unit contains sparse MI =15 cm, five of which range in composition from 60.0 to 63.6% SiO2; many contain hb xls (see also, Grove and Donnelly-Nolan, 1986). Phenocrysts: =5% 1–3 mm plag; 1–2% 1–2 mm opx. Overlies units anh, anr, and bwh; underlies unit rh and surficial unit p. May have been erupted early in latest glaciation. 40Ar/39Ar age is 28±5 ka (table 1). Sectors J, K. *GRI Source Map ID 7411.* (*Lava Beds NM*).

PEaib - Andesite of Indian Butte (late Pleistocene)

Variably porphyritic andesite and basaltic andesite (56.1–59.5% SiO2; avg of 11 = 57.6%) that was erupted from Indian Butte, adjacent cinder cone to west, and additional cones farther to north-northwest. Covers significant area on upper northeast flank of MLV. Phenocrysts: 1–10% 1–4 mm plag+ol; plag>ol. Overlies all adjacent units except mna, bvc, rgm, and surficial unit p. 40Ar/39Ar age is 22±13 ka (table 1). Sectors J, K, L. *GRI Source Map ID 7411.* (*Lava Beds NM*).

PEbwh - Basalt west of Mount Hoffman (late Pleistocene)

Sparsely to moderately porphyritic basalt (52.9% SiO2) flow and cone partially buried under west edge of Mount Hoffman rhyolite flow (unit rmh). Phenocrysts: 2–3% plag, mostly 1 mm, some =3 mm; a few 1 mm ol xls; scattered 2–3 mm clots of plag+ol. Groundmass contains abundant smaller plag+ol xls, plag>ol. Overlies unit anr; underlies unit rmh and surficial unit p. Sectors J, K. *GRI Source Map ID 7411.* (*Lava Beds NM*).

PEbuc - Basalt under Callahan Flow (late Pleistocene)

Very porphyritic basalt (50.9% SiO2) flow displaying rugged morphology. Was erupted from cinder cone that is surrounded by Callahan Flow (unit mcf). Phenocrysts: 30–40% plag, mostly 2–5 mm; 1–3% 1–3 mm ol. Overlies units rgf, dta, and mfh; underlies units bgd and mcf. Sector G. *GRI Source Map ID 7411.* (*Lava Beds NM*).

PEbci - Basalt of Caldwell Ice Caves (late Pleistocene)

Aphyric basalt (52.8% SiO2) flow, which includes mostly collapsed lava tube that is host to Caldwell Ice Caves near southeast corner of LBNM. Tube and flow directions indicate buried vent(s) to southwest. Overlies units mc, mni, anh, and bng; underlies units aib and bvc. Sector J. *GRI Source Map ID 7411.* (*Lava Beds NM*).

PEmsm - Basaltic andesite south of Mammoth Crater (late Pleistocene)

Sparsely porphyritic basaltic andesite (53.4% SiO2) of north-trending array of several spatter vents bisected by Lava Beds–Medicine Lake road (Forest Road 49) south of Mammoth Crater. Phenocrysts, =3%: 1–4 mm plag; 1 mm ol; plag>ol. Overlies units mhi and asm; underlies unit bmc. Sector I. *GRI Source Map ID 7411.* (*Lava Beds NM*).

PEmts - Basaltic andesite of Three Sisters (late? Pleistocene)

Poorly porphyritic basaltic andesite (54.4% SiO2) in eastern part of LBNM. Apparently was erupted from cluster of small cones in southern part of unit. Vents are atypical, in that they show no apparent alignment, although cones could be interpreted as lying on intersecting northeasterly and northwesterly alignments. Phenocrysts: 1% 1–2 mm plag. Overlies unit bpa; underlies unit bmc. Previously designated as “unit bts” of Donnelly-Nolan and Champion (1987). Sector J. *GRI Source Map ID 7411.* (*Lava Beds NM*).

PEasb - Andesite of Schonchin Butte (late Pleistocene)

Sparsely porphyritic andesite (56.8–57.4% SiO2; avg of 3 = 57.2%) block lava flow (Schonchin Flow) that has steep margin, rugged morphology, and little vegetative cover. Unit also includes tephra erupted from Schonchin Butte, which is prominent landmark in LBNM and is location of monument fire lookout (foot trail to top). Phenocrysts: approx 2% 1–4 mm plag; <1% 1 mm ol. More extensive description was given in Donnelly-Nolan and Champion (1987); see also, Mertzman (1977a). Schonchin Flow overlies unit msc; in hole dug at south edge of the basalt of Mammoth Crater (unit bmc), tephra of this unit overlies unit mhi; unit underlies units bmc and bc. 40Ar/39Ar age is 65±23 ka (table 1). Sector I. *GRI Source Map ID 7411.* (*Lava Beds NM*).

PEbpa - Basalt of The Panhandle (late Pleistocene)

Fine grained, diktytaxitic basalt (49.6–51.0% SiO2; avg of 3 = 50.4%). Shows evidence at its northeast margin of having flowed into ancient Tule Lake; this and its petrographic and morphologic similarity to overlying unit bmc, which also flowed into ancient Tule Lake, make two units (bpa and bmc) difficult to distinguish in field. Vent is unknown but presumably is located south or southwest of outcrop area. Previously understood (see Donnelly-Nolan and Champion, 1987) as two units ("bo" and "bpa"), but subsequent paleomagnetic sampling (D.E. Champion, unpub. data, 1984) and chemical analyses (this study) indicate that more mantled lava (previous "unit bo") is same as lava having more youthful appearance (previous "unit bpa"). Unit is cut by open ground crack (Big Crack) that also breaks unit bmc. Phenocrysts: <0.5% 1 mm plag; rare 1 mm ol. Underlies units mts and bmc; overlies unit mj (Juniper Butte). Sector J. *GRI Source Map ID 7411.* (*Lava Beds NM*).

PEbeb - Basalt east of Big Sand Butte (late Pleistocene)

Aphyric basalt (51.0% SiO2) that apparently was erupted from partially collapsed lava lakes located approx 1 km east of Big Sand Butte. Overlies units mes and bls; underlies unit bmc. Sector K. *GRI Source Map ID 7411.* (*Lava Beds NM*).

PEbyb - Basalt of Yellowjacket Butte (late Pleistocene)

Variably porphyritic, chemically variable basalt (49.5–53.1% SiO2) forming very large flow, which has maximum extent of about 32 km northwest to southeast and total volume of 4–5 km3 (Donnelly-Nolan and others, 2005). Was erupted from numerous vents, including five lying along 11-km-long northwest trend, which is intersected at its northwest end by similar number of vents lying along 2-km-long, approximately east-northeast trend. Some of these latter vents possibly are rootless vents over lava tube. Cones in upper vent area have been glaciated. Unit is broken by several faults, primarily in its southwestern part; most trend north-south to northwesterly and are dominantly down to west, including Mayfield Fault. Phenocrysts, variable: from <1% (total) of 1–2 mm plag+ol to =10% (total); includes 1–5 mm plag, 1–2 mm ol, typically plag>>ol; plag+ol commonly appear as 2–4 mm clots, which can give rock spotted look. Texture is sugary and granular to diktytaxitic. Overlies units mrr, b17, bdc, ay, bdb, as, asr, bt, and bl; underlies units ms, bwc, brf, bgc, and abl, as well as glacial-outwash gravel of surficial unit g. 40Ar/39Ar age is 86±14 ka (table 1). Sectors A, L, M. *GRI Source Map ID 7411.* (*Lava Beds NM*).

PEbl - Lake Basalt (late Pleistocene)

Variably porphyritic basalt and basaltic andesite (50.0–56.1% SiO2; avg of 45 = 52.4%) flows and multiple (>15) cones along two trends: one is 15 km long and is north-northwest-trending; other extends approx 5 km east-west across eastern part of caldera floor to east rim of caldera. Unit covers approximately 150 km2 and has an estimated volume of about 3 km3: some is within eastern part of caldera; remainder is east and southeast of caldera on east slope of MLV. Unit is glaciated but is commonly scoriaceous in appearance, having a slightly purplish hue. Four subgroups have been defined by Wagner and others (1995), including sparsely porphyritic lava that has as little as 2–3 percent plag and trace of ol, as well as very porphyritic lava that contains as much as 33 percent phenocrysts consisting of 1–4 mm plag and 1 mm ol, which constitutes =2 percent of rock; plag>>ol; cpx is present but rare. One partially melted granitic inclusion was found. Overlies units obu, omb, reg, rsl, beg, deg, dta, mrs, msp, aug, bac, aac, asr, anr, drs, and bt; underlies units byb, aib, brf, dpc, dm, abl, rh, and rgm, as well as surficial units g, l, t, and p. Three 40Ar/39Ar measurements yield ages of 126±14 ka,

123±27 ka, and 65±10 ka (table 1): of four subgroups of this unit (Wagner and others, 1995), oldest (or "caldera") Lake Basalt has ages of 126±14 and 123±27 ka, but it overlies unit anr (100±3 ka); one age of 65±10 ka was measured on Lake Basalt lava that has same paleomagnetic direction (D.E. Champion, unpub. data, 1995) as southern subgroup of this unit, which underlies unit byb (86±14 ka). Thus, two older measured ages for this unit are too old, and youngest age is too young. However, weighted mean of three ages is 89±13 ka, which fits stratigraphic constraints of ages for underlying unit anr and overlying unit byb. Sectors I, J, K, L, M. *GRI Source Map ID 7411.* (*Lava Beds NM*).

PEbt - Basalt of Tionesta (late Pleistocene)

Aphyric, fine grained, diktytaxitic basalt (48.1–48.4% SiO2; avg of 7 = 48.3%) of primitive composition, as well as low-relief morphology indicative of fluid lava. Pattern of topographic contours and distribution of lava-tube caves indicate source buried to west under younger lavas on east flank of MLV. Unit was formerly (C.A. Anderson, 1941) considered part of the "Warner Basalt," a widespread series of Pliocene basalts making up much of surface of Modoc Plateau. More recent work (for example, Donnelly-Nolan and others, 1996) indicates that the Warner Basalt consists of numerous smaller, but very similar, diktytaxitic-basalt units, many of which are Pleistocene. Numerous north- to north-northeast-trending faults break unit, most of which show little offset or are open ground cracks having no vertical offset. Part of unit (amounting to <2 km2) extends east beyond map boundary. Overlies units omt, obu, rsl, m13, bse, mes, bdb, and probably unit bls; underlies units bl, byb, and bmc, as well as surficial unit g. Sectors K, L. *GRI Source Map ID 7411.* (*Lava Beds NM*).

PEbls - Basalt of Little Sand Butte (late Pleistocene)

Poorly porphyritic basalt (51.1, 51.4% SiO2) that was erupted from Little Sand Butte cinder cone and north-trending spatter rampart on its south flank. Phenocrysts, =1%: 1–2 mm, mostly ol; rare 1 mm plag. Overlies units rcb, m3, and mes; probably overlies unit bng; underlies units beb, aib, and bmc; probably underlies unit bt. 40Ar/39Ar age is 97±13 ka (table 1). Sector K. *GRI Source Map ID 7411.* (*Lava Beds NM*).

PEdrs - Dacite of Red Shale Butte (late Pleistocene)

Moderately porphyritic, low-silica dacite (62.3–64.5% SiO2; avg of 7 = 63.1%) that was erupted from Red Shale Butte at or near east rim of caldera. Unit probably forms bulk of Red Shale Butte, although Lake Basalt (bl) was erupted through (and flowed over) this unit, such that this unit now exists only as half dozen isolated patches. Both this unit and unit bl have been glaciated. Total exposed area extends as far as 6 km west-southwest to east-northeast. Phenocrysts: 5% 1–2 mm plag; =1% 1 mm cpx+opx. Age relation to unit asr is uncertain. Overlies units mrs and aac; underlies units bl and rh, as well as surficial units t and p, latter of which in this area includes late Holocene tephra deposits but dominantly consists of Glass Mountain tephra. K-Ar age of 88±7 ka (table 1) may be too young, on basis of arguments discussed in Donnelly-Nolan and others (1994). Sectors L, M. *GRI Source Map ID 7411.* (*Lava Beds NM*).

PEanr - Andesite of north rim (late Pleistocene)

Poorly porphyritic andesite and subordinate amounts of dacite (57.5–64.3% SiO2; avg of 11 = 60.7%) lava flows that were erupted as fountain-fed flows from several vents that define north rim of Medicine

Lake caldera. At and near caldera rim, unit is glaciated, displaying smooth, sometimes polished and striated surfaces on dull-gray andesite. Farther away from caldera, unit typically displays blocky surface; many individual blocks have black, glassy appearance. Unit covers area approx 15 km southwest-northeast by 5 to 10 km northwest-southeast. Typical phenocrysts: <<1% 1–2 mm plag; rare opx±ol±cpx. Also typical are small lithic fragments of variety of rock types, including white fragments of rhyolite. Two lava flow samples collected on or near north caldera rim are more silicic (62.7, 64.3% SiO2) than other samples and are noticeably more porphyritic, having approx 2% 1–2 mm plag and approx 0.5% pyx. Two MI were collected and analyzed (both contain 55.2% SiO2). Overlies numerous units: in northeastern part of unit, overlies m10, a5, asc, dec, dta, m9, anh, ama, mnm, bnf, bac, bsc, and asm; in northwest, overlies units rgf, rcg, arr, mnl, awh, mbp, a6, dta, muc, and mfh; in southwest, overlies awh, aeg, mug, blh, and mel. In west, unit abuts unit bpw, which is probably older. Underlies units bl, bwh, rmh, btm, dm, mcf, rh, and rlg, as well as surficial units t, l, and p. 40Ar/39Ar age is 100±3 ka (table 1; see also, Donnelly-Nolan and others (1994) for discussion of this age and other argon ages for this unit). Sectors D, E, F, G, H, I, J. *GRI Source Map ID 7411.* (*Lava Beds NM*).

PEbu - Basalt near Undertakers Camp (late Pleistocene)

Sparsely porphyritic basalt (50.4% SiO2) forming two small areas that include lava flow and one vent, both of which are glaciated. At least one additional vent must be buried by younger lavas to north. Phenocrysts: approx 1% 1–2 mm plag; sparse plag+ol clots =1 cm. Also visible in groundmass are <1 mm ol. Overlies units asr and msp; underlies unit dpc and surficial unit t. Sector M. *GRI Source Map ID 7411.* (*Lava Beds NM*).

PEasm - Andesite south of Mammoth Crater (late Pleistocene)

Moderately porphyritic andesite (58.6% SiO2) flow and unnamed cinder cone approx 1.5 km northwest of Aspen Crater. Phenocrysts: 5% 1–4 mm plag; much less 1 mm ol; scattered =0.5 mm clots of plag+ol+cpx. Overlies units bcu, bst, b9, mhi, mnm, and bac; underlies units anr, msm, bmc, and mna. Sectors I, J. *GRI Source Map ID 7411.* (*Lava Beds NM*).

PEbsc - Basalt southwest of Cinder Butte (late Pleistocene)

Aphyric basalt (52.1% SiO2) that has both aa morphology and youthful appearance, which belie its true age (older than unit anr). Very small outcrop area. Vent is unknown and presumably is buried by unit anr. Overlies unit asc; underlies units anr and mcf. Sector G. *GRI Source Map ID 7411.* (*Lava Beds NM*).

PErng - Rhyolite northwest of Glass Mountain (late Pleistocene)

Aphyric rhyolite (71.1% SiO2) found as large (as large as 1.5 m) blocks adjacent to Glass Mountain (unit rgm) domes 6, 7, and 8 (6th, 7th, and 8th domes of unit rgm north of main Glass Mountain lava flow). Blocks are most abundant immediately west of dome 7 and south of southwest corner of dome 8. No continuous outcrop is visible because area is mostly buried by Glass Mountain pumice of surficial unit p. Underlies unit rgm and surficial unit p. K-Ar age is 105±3 ka (table 1). Sector K. *GRI Source Map ID 7411.* (*Lava Beds NM*).

PEasr - Andesite of south rim (late Pleistocene)

Aphyric to poorly porphyritic andesite (60.3–62.0% SiO2; avg of 5 = 61.4%) that was erupted from arc of vents along south rim of Medicine Lake caldera. Southern analogue of the andesite of north rim (anr). Covers more than 20 km2 of upper south flank of MLV. Appears to make up bulk of Medicine Mountain. Vents for unit as, and probably unit aeg, are buried beneath this unit. Locally steep areas, particularly on north edge and east end of Medicine Mountain, probably resulted from glacial erosion. Area of relatively gentle, irregular topography on north flank of Medicine Mountain, at southeast end of Medicine Lake, likely is a landslide made up entirely of this unit; it extends approx 1 km south of lake and is bounded on east by unit bl and on west by till of unit t. Most private cabins adjacent to Medicine Lake are located in this area. Except for its southernmost lobes, which still retain their carapace of glassy blocks, most of unit exhibits evidence of glacial ice (for example, striations; top of flow removed; glacial lakes such as Bullseye Lake; presence of meadows; and till that includes low morainal ridges; all present about 3 km south-southeast of Medicine Lake). Phenocrysts, typically =1%: mostly 1–2 mm plag, some =4 mm, elongate; rare 1 mm opx, cpx, ol(?). Age relation to units anr and drs is uncertain, but, on basis of argon ages, this unit is older. Similarity of paleomagnetic direction (D.E. Champion, unpub. data, 2003) between this unit and unit anr, as well as their distinctive high-Na2O contents, suggests that they are close in age. Overlies units m11, m12, m14, m16, m19, b11, dwm, bsp, bph, mug, aeg, ay, msp, as, brh, and aac; probably underlies unit bu; underlies units bl, byb, ms, bgc, and abl, as well as surficial units t and l. 40Ar/39Ar age is 124±3 ka (table 1); see also, Donnelly-Nolan and others (1994) and Donnelly-Nolan and Lanphere (2005) for additional data. Sectors A, B, C, D, E, M. *GRI Source Map ID 7411.* (*Lava Beds NM*).

PEbnf - Basalt northeast of Fourmile Hill (late Pleistocene)

Sparsely porphyritic basalt (52.3% SiO2) consisting mostly of at least three N. 5° E.–aligned spatter cones approx 1.5 km northeast of Fourmile Hill. Phenocrysts: 2–3% 1 mm plag+ol, plag>>ol. Underlies unit anr; overlies unit mnm. Sector H. *GRI Source Map ID 7411.* (*Lava Beds NM*).

PEbsl - Basalt south of Little Glass Mountain (late Pleistocene)

Nearly aphyric basalt (49.3% SiO2) that was erupted from vent built on north end of vent cone for unit bep. Vent is located just south of Little Glass Mountain rhyolite flow (unit rlg), which may have buried additional vents. Fluid flow traveled southwest in two lobes around preexisting obstacles. Phenocrysts, rare: 1 mm plag+ol. Overlies units orr, rgf, m15, m18, b14, mnd, dta, mwg, mdp, mug, aeg, and bnp; underlies units bup, mpp, and rlg. Sectors B, C, D. *GRI Source Map ID 7411.* (*Lava Beds NM*).

PEaac - Andesite of Alcohol Crater (late Pleistocene)

Porphyritic andesite (58.0–58.5% SiO2; avg of 4 = 58.2%) flow and vents in eastern part of caldera. Alcohol Crater may represent vent area for this unit, as well as for unit bl, both of which have been excavated by ice at crater. Small window of this unit is exposed in canyon of Paynes Creek, where it underlies unit asr. Phenocrysts: 5% 1–2 mm plag; =1% 1 mm ol. Overlies unit bac; underlies units asr, bl, and rh, as well as surficial unit l (in this area, lake deposits in Alcohol Crater and in adjacent depression to north); probably underlies unit drs. 40Ar/39Ar age is 114±5 ka (table 1). Sectors L, M. *GRI Source Map ID 7411.* (*Lava Beds NM*).

PEbac - Basalt of Aspen Crater (late Pleistocene)

Sparsely porphyritic basalt (50.1–51.8% SiO2; avg of 5 = 50.8%), in three separate, relatively small outcrop areas, both within caldera and on north flank of MLV. One area is in caldera at southeast edge of Arnica Sink; another lies between Mount Hoffman and Aspen Crater; and third and smallest patch is approx 2 km northwest of Aspen Crater. One vent location is unknown but is probably on north caldera rim under unit rmh. Pyroclastic deposits from probable explosive activity at Aspen Crater likely were removed by glacial ice; small unmapped deposit of glacial till overlies unit and is exposed in roadcut approx 1 km south-southwest of Aspen Crater. Phenocrysts: 1–3% 1–2 mm plag+ol, plag>ol; occasional 2–3 mm plag+ol clots. Overlies units m9, m10, and mnm; underlies units aac and bl; presumably underlies unit rh, and surficial unit p within caldera; presumably underlies units asm, anr, aib, and mna north of caldera. Sectors I, J, K, L. *GRI Source Map ID 7411.* (*Lava Beds NM*).

PEbrh - Basalt of Red Hill (late Pleistocene)

Nearly aphyric basalt (50.6% SiO2) that was erupted from multiple spatter vents aligned approx N. 35° E., largest of which is Red Hill. Unit occupies three separate outcrop areas, each with its own vent(s). Phenocrysts: sparse 1 mm plag xls. Abundant <1 mm plag+ol visible in groundmass. Overlies units m17, acc, mug, and aeg; underlies units asr and bgc. Sectors B, C. *GRI Source Map ID 7411.* (*Lava Beds NM*).

PEawl - Andesite west and north of Little Glass Mountain (late Pleistocene)

Sparsely porphyritic andesite (58.5% SiO2) flow that was erupted from cone at northwest edge of Little Glass Mountain. Flow is partially surrounded by Little Glass Mountain rhyolite (unit rlg) and is nearly buried by initial pumice eruption of unit rlg. Flow contains fine-grained MI to 8 cm in size, two of which contain 50.2 and 51.6% SiO2. Phenocrysts: 2–3% 1–2 mm plag; 1% 1 mm ol; rare cpx. Overlies units oap and bnp; probably younger than unit bpw; underlies units mpp and rlg, as well as surficial unit l. Sectors D, E. *GRI Source Map ID 7411.* (*Lava Beds NM*).

PEmnm - Basaltic andesite north of Medicine Lake (late Pleistocene)

Sparsely porphyritic basaltic andesite (56.4–57.6% SiO2; avg of 8 = 56.9%) exposed in three areas, smallest of which (inside caldera) is probably part of vent cone. Other two areas lie to north, southeast of southeast margin of Callahan Flow (unit mcf). Larger, more westerly area is broken by north-northeast-trending fault that has =5 m of offset, down to east. Fault appears to be part of zone of northeast-trending faulting that extends across west and north sides of MLV. Phenocrysts: 1–2% of mostly 1 mm plag, some larger; minor 1 mm ol. Overlies units asc, dec, bcu, ama, and mhi; faulted against older units rec and rse. Underlies units bnf, bac, asm, anr, bmc, and bec. 40Ar/39Ar age of 75±8 ka (not listed in table 1) is apparently too young, on basis of its position underneath unit anr; see Donnelly-Nolan and others (1994) for discussion of argon ages of units; see also, Donnelly-Nolan and Lanphere (2005) for additional data. Sectors G, H, I. *GRI Source Map ID 7411.* (*Lava Beds NM*).

PEas - Andesite of south flank (late? Pleistocene)

Moderately porphyritic andesite (57.5–58.0% SiO2; avg of 3 = 57.8%) lava flow, probably from vent(s) under Medicine Mountain. Phenocrysts, approx 5%: mostly 1–3 mm plag; includes approx 1% 1 mm ol.

Overlies units bet and bsh, as well as three isolated cinder cones (units b11, b13, m19); underlies units asr, byb, ms, and bgc, as well as surficial unit g. Sectors A, M. *GRI Source Map ID 7411.* (*Lava Beds NM*).

PEbpw - Basalt near Pumice Stone Well (late Pleistocene)

Sparsely porphyritic basalt (51.6% SiO2) of relatively young flow and cones. Vents located just northwest of Little Glass Mountain. Two major cones are aligned N. 40° E. Flow extends nearly 8 km northwest from northwest edge of Little Glass Mountain. Flow front is unusually high (at least 60 m) for unit of basaltic composition. Overlies units oap, obw, atm, mtr, anl, awh, and dta; probably also overlies surficial unit g of Tamarack Flat, which was likely deposited by flood that followed eruption of unit dta (Donnelly-Nolan and Nolan, 1986). Underlies units rlg and surficial unit p; may underlie unit awl; age relation to unit anr is uncertain, but unit probably underlies unit anr. Sector E. *GRI Source Map ID 7411.* (*Lava Beds NM*).

PEmel - Basaltic andesite east of Little Glass Mountain (late? Pleistocene)

Sparsely porphyritic basaltic andesite (55.8% SiO2) lava flow and spatter vents. Although glaciation has disturbed unit, vents appear to be aligned approximately N. 50° E. Phenocrysts: 2–3% 1–3 mm plag; <1% 1 mm ol. Overlies units a8, mug, and aeg; underlies unit anr. Sector D. *GRI Source Map ID 7411.* (*Lava Beds NM*).

PEmhi - Basaltic andesite of Hippo Butte (late Pleistocene)

Sparsely porphyritic basaltic andesite (54.4–56.1% SiO2; avg of 7 = 55.4%) lava flow and cones. Unit was erupted from Hippo Butte and from smaller cone south of Mammoth Crater. Rocks from two outcrop areas have similar chemical compositions. Most samples from Hippo Butte contain approx 1–2% phenocrysts: 1 mm plag, some larger plag occasionally; occasional 1 mm ol. Samples from smaller vent are more porphyritic, having 2–3% phenocrysts: 1–2 mm plag+ol, plag>ol. Overlies units m2, a1, awb, and men; may underlie unit mnm; underlies units asm, msm, and bmc. Previously designated as “unit bhb” of Donnelly-Nolan and Champion (1987), although this unit is more extensive than “unit bhb.” Sectors H, I. *GRI Source Map ID 7411.* (*Lava Beds NM*).

PEbts - Basalt of Three Sisters (late? Pleistocene)

Moderately porphyritic basalt (51.8–52.2% SiO2; avg of 4 = 52.0%) that was erupted from several cinder cones, including three north-south aligned cones of Three Sisters (in northwestern part of map area). Two additional vents lie slightly north-northwest of three main cones, and two others are located to northwest and northeast. Phenocrysts: 3–5% 1–2 mm plag+ol, some in 2–3 mm clots; plag=ol. Overlies all adjacent units (otb, oap, aes, aut, b2, b3, dta, surficial unit g). Sectors F, G. *GRI Source Map ID 7411.* (*Lava Beds NM*).

PEmen - Basaltic andesite of Eagle Nest Butte (late Pleistocene)

Sparsely porphyritic basaltic andesite flow and cinder cones (52.4–53.8% SiO2; avg of 10 = 53.2%). Vents are Eagle Nest Butte and Bearpaw Butte. Phenocrysts: approx 1% 1 mm plag, some plag =3

mm; rare 1 mm ol; ol+plag in 1 cm clots. Overlies units msc, awf, awb, and m1; underlies units mhi, bmc, bdh, bbr, and mcf. 40Ar/39Ar age is 114±10 ka (table 1). Sectors H, I. *GRI Source Map ID 7411.* (*Lava Beds NM*).

PEbnp - Basalt near Paint Pot Crater (late? Pleistocene)

Very porphyritic basalt (49.3, 49.4% SiO2) flow that was erupted from partially buried cone east of Paint Pot Crater. Largest outcrop area is southwest of Paint Pot Crater flow (unit mpp). Phenocrysts: approx 15% 1–5 mm plag; approx 3% 1–3 mm ol; common plag+ol clots =1 cm across. Overlies units orr, mnd, mwg, mdp, bwd, and b12; underlies units awl, bsl, bup, mpp, and rlg. Sectors C, D. *GRI Source Map ID 7411.* (*Lava Beds NM*).

PEmfh - Basaltic andesite of Fourmile Hill (late or middle Pleistocene)

Sparsely porphyritic basaltic andesite (54.1–55.7% SiO2; avg of 6 = 55.3%) lava flow that was erupted from two northwest-aligned cinder cones and flowed down northwest flank of MLV. Fourmile Hill is larger and more southerly of two vents. Flow covers area of approximately 5 km by 10 km. Phenocrysts, 1–2%: 1–2 mm plag; 1 mm ol; plag>ol. Overlies adjacent units rgf, m4, m6, m8, bea, mnl, dsk, anl, mbp, and dta; directly underlies only units buc and anr. K-Ar age is 130±36 ka (table 1). Sectors F, G. *GRI Source Map ID 7411.* (*Lava Beds NM*).

PEm1 - Basaltic andesite spatter vent west-northwest of Bat Butte (late or middle Pleistocene)

Porphyritic basaltic andesite (53.0% SiO2) of single isolated spatter cone in LBNM, approx 1 km west-northwest of Bat Butte. Cone is broken down and mostly oxidized, suggesting that it is relatively old. Phenocrysts, approx 20%: mostly 1–2 mm plag; some oxidized 1 mm ol; rare plag+ol+cpx clots =4 mm. Small MI as large as 1 cm were observed in hand specimen. Underlies surrounding unit men. Sector H . *GRI Source Map ID 7411.* (*Lava Beds NM*).

PEbdp - Basalt of Doe Peak (middle Pleistocene)

Moderately porphyritic, diktytaxitic basalt (48.9, 49.1% SiO2) forming small lava flow on lower northwest flank of Doe Peak, as well as somewhat larger lava flow about 2 km southwest, adjacent to paved Harris Spring Road (Forest Road 15); vents trend approx N. 55° E. Both outcrop areas are mantled with pumice, and vents in both areas are broken down and eroded. Coarse diktytaxitic texture. Phenocrysts: 2–5% elongate 1–4 mm plag; <0.5% 1 mm ol. Overlies units mdp and bwd. Sector C. *GRI Source Map ID 7411.* (*Lava Beds NM*).

PEawb - Andesite of Whitney Butte (middle Pleistocene)

Moderately porphyritic andesite (58.4% SiO2) that was erupted from Whitney Butte at northern edge of late Holocene Callahan Flow (unit mcf). Cut by north- and northeast-trending normal faults whose offsets are more commonly down to east than down to west. Faulting has revealed flow thicknesses of at least 10 m, although flow margins are typically 2–3 m high. Phenocrysts: approx 3–5% 1–6 mm plag; rare 1

mm ol. Overlies units ob, dta, mwd, bnw, and awf; underlies units men, mhi, bmc, bgd, and mcf. Sectors G, H. *GRI Source Map ID 7411.* (*Lava Beds NM*).

PEama - Andesite southwest of Mammoth Crater (middle Pleistocene)

Sparsely porphyritic andesite (56.7, 57.4% SiO2) that was erupted from cinder cone approx 4 km southwest of Mammoth Crater. Phenocrysts: 1–2% 1–2 mm plag; less abundant ol. Overlies unit dec; underlies units mnm, anr, and bmc. Sector I. *GRI Source Map ID 7411.* (*Lava Beds NM*).

PEbnb - Basalt north of Burnt Lava Flow (middle Pleistocene)

Moderately porphyritic basalt (49.2% SiO2) flow and cones north of Burnt Lava Flow (unit abl). Phenocrysts: approx 5% 1 mm plag+ol, plag>ol. Probably overlies unit msp; underlies units brf and abl. Sector M. *GRI Source Map ID 7411.* (*Lava Beds NM*).

PEbng - Basalt northeast of Glass Mountain (middle? Pleistocene)

Aphyric basalt (48.4–50.8% SiO2; avg of 6 = 49.4%) whose primary vent(s) is (are) buried by younger flows above 4,900 ft (1,494 m) elevation on northeast flank of MLV. Two additional satellite vents aligned northeast are located in and near southeast corner of LBNM. Overlies units rsl, m3, bei, bco, bse, and anh; underlies units bci, aib, and bvc; probably underlies unit bls. See description of “unit db” in Donnelly-Nolan and Champion (1987). Sectors J, K . *GRI Source Map ID 7411.* (*Lava Beds NM*).

PEmuc - Basaltic andesite under Callahan Flow (middle Pleistocene)

Porphyritic basaltic andesite (52.9–53.1% SiO2; avg of 3 = 53.0%) lava flow and cinder cone approx 1.5 km west-southwest of Cinder Butte. Most of unit lies outside of much younger Callahan Flow (unit mcf), but one small outcrop area is surrounded by unit mcf. Unit is dropped down to southeast by northeast-trending fault. Phenocrysts: 10–15% 1–4 mm plag; 1% 1 mm ol. Overlies unit mnl; underlies units anr and mcf. Presence of unit dta on unit mnl but not on this unit suggests that this unit is younger than unit dta. Sector G. *GRI Source Map ID 7411.* (*Lava Beds NM*).

PEa1 - Andesite cone west of Crescent Butte (middle? Pleistocene)

Sparsely porphyritic andesite (57.4% SiO2) cinder cone adjacent to Crescent Butte (unit m2) and just northeast of Hippo Butte. Cone has been quarried and displays mostly red, oxidized cinders and bombs. Phenocrysts: approx 2% 1–4 mm plag; rare 1 mm ol. Age relation to unit m2 is unknown. Underlies unit mhi. Sector I. *GRI Source Map ID 7411.* (*Lava Beds NM*).

PEaug - Andesite under Glass Mountain (middle Pleistocene)

Sparsely to moderately porphyritic andesite and basaltic andesite (53.6–58.3% SiO2; avg of 4 = 55.1%) lava flow and at least three unnamed cinder cones that are mostly mantled by pumice from late Holocene eruption of Glass Mountain. Unit includes strip of basaltic andesite flow directly east of Glass

Mountain, as well as another directly west of northernmost domes of Glass Mountain (unit rgm). Phenocryst contents vary: three samples have 1–5% plag+ol xls, typically 1–2 mm, plag>ol. Overlies units reg, beg, and deg; probably overlies unit dta; may overlie unit anh; underlies units aib and rgm, as well as surficial unit p. Sectors K, L. *GRI Source Map ID 7411.* (*Lava Beds NM*).

PEm16 - Basaltic andesite cone north-northeast of Six Shooter Butte (middle Pleistocene)

Nearly aphyric basaltic andesite (55.7% SiO2) cinder cone approx 3 km north-northeast of Six Shooter Butte. Phenocrysts, <1%: 1 mm plag; 1–2 mm ol. Underlies surrounding unit asr. Sector A. *GRI Source Map ID 7411.* (*Lava Beds NM*).

PEawf - Andesite west of Fleener Chimneys (middle Pleistocene)

Glassy andesite (60.8% SiO2) lava flow that has highly irregular, blocky surface; flow margin is 10–20 m high. Vent is buried by younger flows to south. Phenocrysts rare, <1%: =1 mm ol+plag. Rock typically contains small (=1 cm) inclusions, mostly MI but also xenoliths. Ash-flow tuff of unit dta is lacking on top of this unit, while at same time is found immediately to north, farther from vent area of unit dta, indicating that this unit overlies unit dta. Also overlies units obg, opt, bwg, mwd, and adh; probably overlies unit bnw; underlies units awb, men, and bdh. Sector H. *GRI Source Map ID 7411.* (*Lava Beds NM*).

PEblh - Basalt of Little Mount Hoffman (middle Pleistocene)

Porphyritic basalt (52.1% SiO2) of glaciated cinder cone just northeast of Little Glass Mountain, on or near poorly defined west rim of caldera. Top of cone provides spectacular view, primarily to south, west, and north, and overlooks the late Holocene Little Glass Mountain rhyolite flow (unit rlg), with Mount Shasta about 50 km away on horizon behind it. Phenocrysts, approx 15%: plag, 1 mm to 1 cm; 1–3 mm ol; plag>ol. Overlies units mlh, awh, and aeg; underlies unit anr. 40Ar/39Ar age is 146±11 ka (table 1). Sector E. *GRI Source Map ID 7411.* (*Lava Beds NM*).

PEaut - Andesite under Three Sisters (middle Pleistocene)

Sparsely porphyritic andesite (57.4% SiO2) that flowed over, and was later displaced by, northwest-trending fault in northwest corner of map area. Despite single andesite chemical analysis, much of unit appears to be more mafic. Vent location is unknown and presumably is buried under Three Sisters lava (unit bts). Phenocrysts: 1–2% 1–2 mm plag+ol. Overlies units otb, ob, and dta; underlies unit bts. Sectors F, G. *GRI Source Map ID 7411.* (*Lava Beds NM*).

PEm2 - Basaltic andesite of Crescent Butte (middle Pleistocene)

Poorly porphyritic basaltic andesite (54.5% SiO2) of Crescent Butte cinder cone, oxidized. Located short distance northwest of headquarters of LBNM. Phenocrysts: 1% 1 mm plag+ol, plag>ol. Underlies units mhi and bmc. Age relation to adjacent isolated andesite cinder cone (unit a1) is unknown. Sectors I, J. *GRI Source Map ID 7411.* (*Lava Beds NM*).

PEbdb - Basalt of Damons Butte (middle Pleistocene)

Variably porphyritic basalt (47.8–48.3% SiO2; avg of 13 = 48.0%) at easternmost edge of MLV; only western part of unit is shown on map. Unit may be a back-arc basalt not directly related to MLV, although it is age equivalent. Several (about 5) spatter vents form north-northeast trend, approx 4 km east of map boundary. Fine grained and aphyric to moderately porphyritic. Phenocrysts (when present): =5% 1–2 mm ol+plag, commonly in clots =1 cm that give rock a spotted appearance; in addition, single 5 mm cpx+plag clot present. Overlies unit ob; underlies units bt and byb. 40Ar/39Ar age is 144±15 ka (table 1). Sectors K, L. *GRI Source Map ID 7411.* (*Lava Beds NM*).

PEbnw - Basalt north of Whitney Butte (middle Pleistocene)

Moderately porphyritic basalt (50.7% SiO2) of eroded, northeast-trending set of small spatter cones; no lava flow visible. Phenocrysts, 3–5%: 1–6 mm ol+plag, ol>>plag. Underlies, and is nearly surrounded by, unit awb; probably underlies unit awf. Sector H. *GRI Source Map ID 7411.* (*Lava Beds NM*).

PEmsc - Basaltic andesite of Semi Crater (middle Pleistocene)

Porphyritic basaltic andesite (55.0, 55.5% SiO2) lava flows that were erupted from now-isolated and partially buried cinder and spatter cone of Semi Crater, which is surrounded on three sides by unit bc and is invaded on east by tongue of Schonchin Flow (unit asb). Phenocrysts, 10%: plag =5 mm; ol =2 mm; plag>ol; plag+ol±cpx clots =7 mm. Overlies unit bcb; underlies units men, asb, bmc, bc, bdh, and bbr. May be younger than unit dta, which does not overlie this unit. Previously designated “unit bsc” by Donnelly-Nolan and Champion (1987). Sectors H, I. *GRI Source Map ID 7411.* (*Lava Beds NM*).

PEanh - Andesite northeast of Mount Hoffman (middle Pleistocene)

Porphyritic andesite (57.7, 58.0% SiO2) flow exposed in three separate areas and extending at least 11 km from northeast edge of unit rmh, which directly overlies this unit. Vent is not exposed and presumably is buried to south or southwest. Unit is cut by two small northeast-trending faults. Phenocrysts: approx 15% 1–4 mm plag; 1–3% 1–2 mm ol. Overlies isolated basaltic andesite cone of unit m10; in outcrop area immediately northeast of Mount Hoffman, underlies units anr, aib, rmh, rgm, and surficial unit p; probably underlies unit aug in area west of northernmost domes of unit rgm; in two smaller areas southeast of Caldwell Butte, underlies units bng, bci, and aib. See also description of “unit pa” in Donnelly-Nolan and Champion (1987). Sectors J, K. *GRI Source Map ID 7411.* (*Lava Beds NM*).

PEbcb - Basalt of Canby Bay (middle Pleistocene)

Sparsely porphyritic basalt (50.0% SiO2), in northern part of LBNM. Phenocrysts: 2% 1–3 mm plag; rare ol =3 mm. Petrographically distinct because of its more abundant phenocrysts when compared to adjacent and morphologically similar, but nearly aphyric, lava of the basalt of Mammoth Crater (bmc). Underlies all adjacent units (msc, bmc, bc, bdh) except unit bhp to north, which it overlies. Vent is unknown and presumably is buried to south under younger lava flows. Sector I. *GRI Source Map ID 7411.* (*Lava Beds NM*).

PEb4 - Basalt of Caldwell Butte (middle? Pleistocene)

Very porphyritic basalt (51.6% SiO2) of Caldwell Butte cinder cone, as well as of satellite vent, Caldwell Minor, on its north flank. Lava flows, if present, are entirely buried by younger lavas. Phenocrysts: approx 20% 1–4 mm plag; 1% 1–2 mm ol. Underlies unit bvc. Sector J. *GRI Source Map ID 7411.* (*Lava Beds NM*).

PEmsp - Basaltic andesite east and northeast of Shotgun Peak (middle Pleistocene)

Poorly porphyritic basaltic andesite (52.6–53.6% SiO2; avg of 5 = 53.2%) lava flows and cinder cones between Burnt Lava Flow (unit abl) and southeast margin of Medicine Lake caldera. Unit is glaciated in upper part and is partially buried by adjacent lava flows. Phenocrysts, =1%: 1–2 mm plag+ol; plag>ol. Overlies units bsp and ds; underlies units bnb, asr, bu, bl, brf, dpc, and abl. 40Ar/39Ar age is 168±7 ka (table 1). Sectors L, M. *GRI Source Map ID 7411.* (*Lava Beds NM*).

PEbei - Basalt east of Indian Butte (middle Pleistocene)

Porphyritic basalt (51.7% SiO2) exposed in small area about 3 km southeast of Cougar Butte. Vent location unknown. Phenocrysts: 5–10% =3 mm, mostly plag; approx 1% 1–2 mm ol. Underlies unit aib; probably underlies unit bng. Sector K. *GRI Source Map ID 7411.* (*Lava Beds NM*).

PEbwd - Basalt west of Doe Peak (middle Pleistocene)

Porphyritic basalt (51.6, 53.0% SiO2; avg = 52.3%) flow and cone along southwest edge of map area. Phenocrysts: =5% plag, typically 1–2 mm; some elongate plag =5 mm; =1% 1 mm ol. Overlies units orr, ael, mrl, mdp, and dls; underlies units bdp and bnp. Sector C. *GRI Source Map ID 7411.* (*Lava Beds NM*).

PEadh - Andesite near Devils Homestead (middle Pleistocene)

Variably porphyritic andesite (56.5–57.8% SiO2; avg of 3 = 57.3%) lava flows exposed at and near base of Gillem Fault in northwestern part of LBNM. Three flows are exposed at and near Devils Homestead overlook: uppermost is least porphyritic (1–3% phenocrysts); middle flow contains 3–5% phenocrysts; and top of lowermost flow is most porphyritic (5–10% phenocrysts). All three contain 1–4 mm plag; 1–2 mm ol; plag>>ol. Additional small patches of unit are found farther north along Gillem Fault. In two places near Gillems Camp at north edge of LBNM, uppermost flow of unit overlies unit bgf. Both units flowed against preexisting fault scarp and were subsequently uplifted by more recent movements. Vent is unknown and presumably is buried farther south. Underlies units awf and bmc; overlies unit bgf. 40Ar/39Ar age of uppermost flow is 171±4 ka (table 1). See Donnelly-Nolan and Champion (1987) for additional information; mapped as “unit adha” on their map. Sector H. *GRI Source Map ID 7411.* (*Lava Beds NM*).

PEb9 - Basalt cone north of Aspen Crater (middle Pleistocene)

Porphyritic basalt (50.5, 51.1% SiO2) cinder cone approx 2.5 km southeast of Mammoth Crater and an equal distance north-northeast of Aspen Crater. Phenocrysts, 10–15%: mostly 1–3 mm plag; includes approx 2–3% 1–2 mm ol; rare cpx. Underlies units asm and mna. Sector J. *GRI Source Map ID 7411.* (*Lava Beds NM*).

PEmrs - Basaltic andesite of Red Shale Butte (middle Pleistocene)

Poorly porphyritic basaltic andesite (53.0–54.0% SiO2) exposed as two small patches at base of Red Shale Butte. Phenocrysts: <1% 1 mm plag, some plag =4 mm; rare 1 mm ol. Underlies units drs, bl, and rgm. Sector L. *GRI Source Map ID 7411.* (*Lava Beds NM*).

PEmes - Basaltic andesite of East Sand Butte (middle? Pleistocene)

Porphyritic basaltic andesite (54.6% SiO2) lava flow that surrounds its own vent, East Sand Butte. Cinder cone has been quarried by railroad mining, exposing interior of cone, which contains both partially melted silicic inclusions and MI (two samples, 48.3, 49.5% SiO2); see also, A.T. Anderson (1976). Phenocrysts: 5% 1–4 mm plag; 1% 1–2 mm ol. Underlies all adjacent units (beb, bls, bt, bmc). Sector K. *GRI Source Map ID 7411.* (*Lava Beds NM*).

PEaeg - Andesite east of Grasshopper Flat (middle Pleistocene)

Poorly porphyritic andesite (56.4–57.5% SiO2; avg of 3 = 57.1%) flow and glaciated caldera-rim vent cones. Extends south and south-southwest from caldera rim as far as 8 km. Phenocrysts: approx 1% mostly 1 mm plag, some larger; minor ol+cpx. Overlies units mug and isolated cinder cones a8, a9, and m15; underlies units mel, brh, bsl, asr, anr, mgf, bgc, and rlg. 40Ar/39Ar age of 236±33 ka (not listed in table 1) is considered too old, on basis of stratigraphic constraints. See Donnelly-Nolan and Lanphere (2005) for additional data. Unit overlies unit mug, which has 40Ar/39Ar age of 180±28 ka (table 1). Sectors B, C, D, E. *GRI Source Map ID 7411.* (*Lava Beds NM*).

PEbtw - Basalt of Twin Sister (middle Pleistocene)

Porphyritic basalt (49.6, 49.8% SiO2) of two cinder cones aligned north-northeast: northern cone was quarried to below ground level by railroad mining before 1980; Twin Sister is unquarried southern cone. Phenocrysts, 10–15%: 1–4 mm ol+plag, large ol more abundant than large plag, small (1 mm) ol less abundant than small (1 mm) plag. Both cones lie east of LBNM and are entirely surrounded by unit bmc. Sector J. *GRI Source Map ID 7411.* (*Lava Beds NM*).

PEds - Dacite of south flank (middle Pleistocene)

Porphyritic, high-silica dacite (69.9% SiO2) lava flow or dome exposed in small outcrop area on upper south flank of MLV at about 6,300 ft (1,920 m) elevation. Vent location is unknown but probably is uphill to north. Rock consists of streaky vitrophyre containing abundant fine-grained MI as much as 20 cm across. Two MI contain 51.2 and 51.3% SiO2. Phenocrysts, host lava: =5% 0.5–3 mm plag; approx 1% =1 mm opx commonly associated with smaller opaque grains; 5% plag+cpx+ol (plag>cpx>ol) are

probably disaggregated fragments of inclusions. Underlies, and is mostly buried by, unit msp. 40Ar/39Ar age of one MI is 159±30 ka (table 1); however, this unit and unit dsk could be part of same eruptive event, on basis of close similarity in chemical composition of both host silicic lava and sampled MI. If so, argon age of this unit likely is too young, whereas argon age of unit dsk (244±20 ka) likely is too old; both are part of approx 200-ka-old dacite event at MLV. Sector M. *GRI Source Map ID 7411.* (*Lava Beds NM*).

PEb5 - Basalt cone southeast of Mammoth Crater (middle? Pleistocene)

Poorly porphyritic basalt (52.1% SiO2) cinder cone just southeast of Mammoth Crater, south of southwest end of Hidden Valley. Phenocrysts: <1% 1–2 mm plag. Underlies units bma and bmc. Sector I. *GRI Source Map ID 7411.* (*Lava Beds NM*).

PEbco - Basalt of Cougar Butte (middle Pleistocene)

Moderately porphyritic basalt (51.2% SiO2) lava flow and Cougar Butte cinder cone, midway up northeast flank of MLV. Phenocrysts: 5% 1–3 mm plag+ol; large ol more abundant than large plag, small ol less abundant than small plag. Overlies unit rcb; underlies units bls and aib; probably underlies unit bng. Sector K. *GRI Source Map ID 7411.* (*Lava Beds NM*).

PEay - Andesite under basalt of Yellowjacket Butte (middle Pleistocene)

Porphyritic andesite (58.5% SiO2) lava flow. Vent is unknown and is presumed to be buried uphill to north. Phenocrysts, 10%: mostly 1–3 mm plag (some elongate); includes approx 2% 1 mm ol+cpx, ol>cpx. Underlies all adjacent units (asr, byb, ms, abl). Sector A. *GRI Source Map ID 7411.* (*Lava Beds NM*).

PEmug - Basaltic andesite under Giant Crater lava field (middle Pleistocene)

Variably porphyritic, from poorly porphyritic to porphyritic, basaltic andesite (53.4–56.6% SiO2; avg of 8 = 55.0%) in part under Giant Crater lavas (unit bgc), although most of unit lies to west and north. Only one vent is exposed, approx 1 km east of Little Mount Hoffman, but others may be present under units aeg, asr, and perhaps anr. Unit is very similar chemically to unit mbp, but unit mbp is overlain by the dacite tuff of Antelope Well (dta). Phenocrysts: 1–15%, dominantly 1–3 mm plag; some plag =5 mm; <1% to 2% ol, typically 1–2 mm. Overlies units rgf, m15, m17, awm, dwm, bel, mlc, mbp, bwl, acc, mwg, mdp, m11, m12, and probably units a8 and a9; underlies units aeg, mel, brh, bsl, asr, anr, bgc, bv5, and mpp, as well as surficial unit g. Stratigraphic relations and drill hole information indicate that this unit overlies unit dta. 40Ar/39Ar age is 180±28 ka (table 1). Sectors B, C, D, E. *GRI Source Map ID 7411.* (*Lava Beds NM*).

PEm10 - Basaltic andesite cone southeast of Aspen Crater (middle Pleistocene)

Nearly aphyric basaltic andesite (53.7% SiO2) cinder cone approx 1.5 km southeast of Aspen Crater. Phenocrysts rare: 1 mm plag. Underlies units anh, bac, anr, and aib. Sector J. *GRI Source Map ID*

7411. (*Lava Beds NM*).

PEb6 - Basalt cone at southeast end of Hidden Valley (middle Pleistocene)

Nearly aphyric basalt (51.4% SiO2) cinder cone less than 1 km southeast of Mammoth Crater and south of southeast end of Hidden Valley. Phenocrysts: rare =4 mm plag. Underlies units bma and bmc. Sector I. *GRI Source Map ID 7411.* (*Lava Beds NM*).

PEbse - Basalt southwest of East Sand Butte (middle Pleistocene)

Aphyric, fine-grained basalt (50.2% SiO2) lava flow. Some tiny plag+ol visible in groundmass. Unit is similar in composition and in stratigraphic position to unit bco, which lies uphill, but this unit exhibits higher MgO content, whereas unit bco has higher Sr content. Underlies all adjacent units (bt, bls, bng). Sector K. *GRI Source Map ID 7411.* (*Lava Beds NM*).

PEm9 - Basaltic andesite cone southwest of Aspen Crater (middle Pleistocene)

Sparsely porphyritic basaltic andesite (55.1% SiO2) cinder cone just southwest of Aspen Crater. Phenocrysts: approx 1% 1 mm plag; <1% 1 mm cpx+ol. Underlies units bac and anr. Sector J. *GRI Source Map ID 7411.* (*Lava Beds NM*).

PEbpb - Basalt of Porcupine Butte and Timber Hill (middle Pleistocene)

Moderately porphyritic basalt (51.3% SiO2) flow that was erupted from two large cinder cones, for which unit is named, on south side of MLV. Cones are aligned N. 25° W., parallel to northwest-trending fault that cuts unit. Phenocrysts, approx 5%: 1–3 mm plag; 1–2 mm ol; plag>ol. Overlies units bdc and mrr; underlies units bwc and bgc. Sectors A, B. *GRI Source Map ID 7411.* (*Lava Beds NM*).

PEm12 - Basaltic andesite cone southwest of Medicine Lake (middle Pleistocene)

Nearly aphyric basaltic andesite (56.6% SiO2) cinder cone just southwest of Medicine Lake. Phenocrysts: <<1% 1 mm plag+cpx+ol xls, plag>cpx+ol. Xenoliths as large as a few mm also present. Underlies units mug, asr, and surficial units t and l. Sectors C, D. *GRI Source Map ID 7411.* (*Lava Beds NM*).

PEa3 - Andesite of Island Butte (middle Pleistocene)

Sparsely porphyritic andesite (57.5% SiO2) of Island Butte cinder cone in southwest corner of LBNM. Phenocrysts: 2% 1–3 mm plag; <1% 1 mm ol. Cone is entirely surrounded by late Holocene Callahan Flow (unit mcf). Sector H. *GRI Source Map ID 7411.* (*Lava Beds NM*).

PEm14 - Basaltic andesite cone southeast of Paynes Springs (middle Pleistocene)

Moderately porphyritic basaltic andesite (53.0% SiO2) cinder cone approx 1 km southeast of Paynes Springs. Glacial till is present on top of cone, but till is not mapped separately. Phenocrysts, =5%: mostly 1–3 mm plag; approx 1% 1–2 mm ol. Underlies unit asr and mapped area of glacial till (surficial unit t) adjacent to cone. Sector M. *GRI Source Map ID 7411.* (*Lava Beds NM*).

PEm7 - Basaltic andesite cone northeast of Aspen Crater (middle Pleistocene)

Porphyritic basaltic andesite (55.1% SiO2) cinder cone approx 1.5 km northeast of Aspen Crater. Phenocrysts: approx 5% 1–4 mm plag; <1% 1–2 mm ol+cpx. Underlies surrounding unit mna. Sector J. *GRI Source Map ID 7411.* (*Lava Beds NM*).

PEmdp - Basaltic andesite of Doe Peak (middle Pleistocene)

Porphyritic basaltic andesite (55.2% SiO2) forming large flow on southwest flank of MLV. Flow was erupted from its vent at Doe Peak, a large cinder cone that has two craters aligned N. 45° E. Phenocrysts, 10%: mostly 1–4 mm plag; minor 1 mm ol. Overlies units odh, oml, obd, rgf, b14, b12, mnd, bwl, and mhm; underlies units mug, bwd, bdp, bnp, and bsl, as well as surficial unit g. Probably younger than unit dta, which is not found on top of unit but is present to south of unit, indicating that it (dta) likely flowed through area now occupied by this unit. Sectors B, C. *GRI Source Map ID 7411.* (*Lava Beds NM*).

PEa5 - Andesite cone east of Fourmile Hill (middle Pleistocene)

Poorly porphyritic andesite (57.4% SiO2) cinder cone approx 2 km east of Fourmile Hill. Phenocrysts: approx 1% 1–2 mm plag+ol, plag>>ol. Cone is completely surrounded by younger unit anr. Sectors H, I. *GRI Source Map ID 7411.* (*Lava Beds NM*).

PEm11 - Basaltic andesite cone west of Medicine Lake (middle Pleistocene)

Moderately porphyritic basaltic andesite (54.2% SiO2) cinder cone approx 1 km west of west end of Medicine Lake; quarried. Phenocrysts: approx 5% 1–3 mm plag+ol, plag>ol. Underlies units mug and asr. Sectors D, E. *GRI Source Map ID 7411.* (*Lava Beds NM*).

PEbdc - Basalt of Deep Crater (middle Pleistocene)

Poorly porphyritic basalt (two analyses, 50.3% SiO2) forming large complex of lava flows and numerous (=10) cinder and spatter vents at south edge of Burnt Lava Flow (unit abl). Vents, including Deep Crater, are aligned from slightly north of east to approx N. 30° W. One lava tube trends southeast from Deep Crater about 3 km, where it is buried by unit byb. Phenocrysts: <1% 1 mm plag+ol, commonly ol>plag. Rock typically is fine grained, having tiny plagioclase crystals that flash in groundmass on a sunny day. Overlies units b16, mrr, and bnr; underlies units bpb, byb, ms, bgc, and abl, as well as surficial unit g. Lack of unit dta on surface of this large unit may suggest that it is younger than unit dta. Sectors A, M. *GRI Source Map ID 7411.* (*Lava Beds NM*).

PEm5 - Basaltic andesite cone north of Aspen Crater (middle Pleistocene)

Moderately porphyritic, very small basaltic andesite (54.2% SiO2) cinder cone less than 2 km north of Aspen Crater. Phenocrysts, 5%: some plag =3 mm, most 1 mm, typically elongate; some 1 mm ol. Underlies unit mna and glacial-outwash gravel of surficial unit g. Sector J. *GRI Source Map ID 7411.* (*Lava Beds NM*).

PEacc - Andesite of Cinder Cone (middle Pleistocene)

Sparsely porphyritic andesite (58.8% SiO2) flow and cone (Cinder Cone) located on south flank of MLV. Phenocrysts: 1–2% 1–2 mm plag; larger plag+ol+cpx clots; minor 1 mm ol. Underlies all adjacent units (mug, brh, bgc). Sector B. *GRI Source Map ID 7411.* (*Lava Beds NM*).

PEmwg - Basaltic andesite west and north of Grasshopper Flat (middle Pleistocene)

Sparsely to moderately porphyritic basaltic andesite (55.0–57.0% SiO2; avg of 6 = 56.1%) consisting mostly of eroded, probably glaciated cinder cones and some adjacent flow rock. Includes one large and three small outcrop areas. Phenocrysts, 2–5%: mostly 1–4 mm plag; minor ol, typically 1–2 mm. Overlies unit rgf and probably unit mnd; underlies units mug, bnp, bsl, bup, and mpp. Sector C. *GRI Source Map ID 7411.* (*Lava Beds NM*).

PEmwc - Basaltic andesite in western Callahan Flow (middle Pleistocene)

Porphyritic basaltic andesite (54.4% SiO2) cone and lava flow forming two kipukas near west edge of late Holocene Callahan Flow (unit mcf). Phenocrysts, 10%: dominantly 1–2 mm plag; includes 2% 1 mm ol. Entirely surrounded by overlying Callahan Flow (unit mcf). Sector G. *GRI Source Map ID 7411.* (*Lava Beds NM*).

PEbcu - Basalt of unnamed crater (middle Pleistocene)

Poorly porphyritic basalt (52.2, 52.5% SiO2) exposed in collapse(?) or explosion(?) pit and in one other small outcrop area about 2.5 km southwest of Mammoth Crater. Unit may have been erupted from unknown vent to south. If crater was created by explosion, pyroclastic deposits were likely removed by glacial ice. Phenocrysts: 1% 1 mm plag; trace 1 mm ol. Underlies units mnm and asm. Sector I. *GRI Source Map ID 7411.* (*Lava Beds NM*).

PEm3 - Basaltic andesite of Big Sand Butte (middle Pleistocene)

Porphyritic basaltic andesite (54.0% SiO2) of Big Sand Butte cinder cone and small satellite cone to northwest. Phenocrysts: 5–10% 1–3 mm plag+ol, plag>ol. Underlies four adjacent basalt units bng, bls, bmc, and bvc. Sector K. *GRI Source Map ID 7411.* (*Lava Beds NM*).

PEmhm - Basaltic andesite adjacent to Harris Mountain (middle Pleistocene)

Sparsely porphyritic basaltic andesite (55.2% SiO2) lava flow. Vent location is unknown and presumably is buried to north or northeast. Phenocrysts, 1–2%: mostly 1–3 mm plag; some clots of plag+ol+cpx. Overlies units odh, oml, and obd; probably overlies unit dta, which is found to south of unit but not on top of it, as would be expected if unit dta were younger; underlies unit mdp and surficial unit g. Sectors B, C. *GRI Source Map ID 7411.* (*Lava Beds NM*).

PEbgf - Basalt west of Canby Cross at Gillem Fault (middle Pleistocene)

Poorly porphyritic basalt (51.4% SiO2) exposed in small upfaulted outcrops at base of Gillem Bluff in northwestern part of LBNM. Unit flowed against preexisting Gillem Fault, then it was covered in part by unit adh; subsequently, both units (bgf, adh) were upfaulted more than 10 m. Phenocrysts: 0.5% 1 mm plag. Younger than Pliocene units obg and omw of Gillem Bluff; underlies unit adh. Older than unit bmc, which flowed against upfaulted outcrops of this unit. See Donnelly-Nolan and Champion (1987) for additional information (on their map, mapped as “unit bwcc”). Sector H. *GRI Source Map ID 7411.* (*Lava Beds NM*).

PEmni - Basaltic andesite north of Indian Butte (middle Pleistocene)

Moderately porphyritic basaltic andesite (54.8, 55.0% SiO2) lava flow exposed in three separate outcrop areas. Also includes vent cone at south end of largest area. Phenocrysts: 3–5% 1–3 mm plag; 1% 1–2 mm ol; sparse plag+ol clots =5 mm. May be younger than unit a4; older than surrounding units bci and aib. Sector J. *GRI Source Map ID 7411.* (*Lava Beds NM*).

PEbph - Basalt of Papoose Hill (middle Pleistocene)

Porphyritic basaltic (49.0, 54.3% SiO2; avg = 51.7%) lava flow, as well as cinder cone for which unit is named. Phenocrysts: 10–15%, mostly plag, 1–4 mm; 1–2% 1–2 mm ol. Overlies units bug, mph, and asn; underlies units asr and bgc. Sectors A, B. *GRI Source Map ID 7411.* (*Lava Beds NM*).

PEasn - Andesite of Snag Hill (middle Pleistocene)

Moderately porphyritic blocky andesite (61.6% SiO2) flow and cinder cone of Snag Hill on south flank of MLV. Phenocrysts, approx 5%: mostly 1–2 mm plag; some =5 mm plag; <1% 1 mm ol. Underlies all adjacent units (bph, bwc, bgc). Sector B. *GRI Source Map ID 7411.* (*Lava Beds NM*).

PEbnr - Basalt north of railroad (middle Pleistocene)

Aphyric, diktytaxitic basalt (47.2% SiO2) flow that covers very small area on lower south flank of MLV, approx 2 km northwest of railroad siding at Lakin and 4 km southeast of Porcupine Butte. Vent location unknown. Overlies unit mrr; nearly surrounded by overlying unit bdc. Sector A. *GRI Source Map ID 7411.* (*Lava Beds NM*).

PEbwl - Basalt west of Lava Crack Spring (middle Pleistocene)

Variably porphyritic basalt (47.5–48.0% SiO2; avg of 5 = 47.7%) exposed primarily as narrow, approx 6-km-long flow west of Lava Crack Spring and southeast of Harris Mountain, as well as separate smaller tongue to east. Unit appears to have flowed against preexisting fault scarp of north- northwest-trending, down-to-east fault; unit is broken by north-trending, down-to-west fault. Phenocrysts: <1% 1–2 mm plag; =5% 1–4 mm plag (typically elongate) and 1 mm ol, plag>ol; plag+ol commonly in small clots. Overlies units ob, obd, and mlc; underlies units mdp and mug, as well as surficial unit g, which in this area forms small alluvial fan that obscures contact area between two lobes of unit. Probably younger than unit dta, which is found farther south on underlying unit obd. Sector B. *GRI Source Map ID 7411.* (*Lava Beds NM*)
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PEdta - Dacite tuff of Antelope Well (middle Pleistocene)

Dacite ash-flow tuff found in many sectors around MLV, which makes it stratigraphically most important unit at MLV. Tuff is widespread unit that washed across preexisting topography, depositing thickly enough in low topographic areas to become welded and so to remain as recognizable unit today. Previously named “andesite tuff” by C.A. Anderson (1941). Analyses of 15 pumice samples range in composition from 63.1 to 67.1% SiO2 (avg 64.9%); 10 whole-rock analyses range in composition from 61.0 to 64.9% SiO2 (avg 63.3%). Sizes of lithic fragments and pumice lumps increase toward caldera (Donnelly-Nolan and Nolan, 1986; Donnelly-Nolan, 1987), indicating intracaldera source, perhaps where Medicine Lake is located or under Medicine Lake Glass Flow (unit dm) on caldera floor north of Medicine Lake. However, nearly all units on rim and floor of present-day caldera are younger than this unit, and so recognition of specific vent site is problematic. Three outcrops of this unit have been found within caldera; all are west-northwest of Medicine Lake and all overlie units mbp and awm. Outcrop at east end of unit awm is remarkable for having flattened, welded pumice lumps that are a meter long but are only 2 to 4 cm thick. This same locality also exhibits sparse lithic fragments and MI as much as 20 cm across. Outcrop appears to be welded and plastered onto northeast-facing slope, as though it was deposited by southwest-directed eruption. Donnelly-Nolan and Nolan (1986) presented evidence that deposition of this unit was followed by catastrophic flooding that cut anastomosing channels, primarily in northwest quadrant of MLV. Most tuff outcrops are present in this quadrant. Some of unit did travel east through caldera-rim gap now filled by unit rh and by Glass Mountain flow (unit rgm). Pieces of ash-flow tuff also are present in ejecta from explosion pits near east edge of the rhyolite of Mount Hoffman (unit rmh), indicating that this unit underlies unit rmh. In addition, single outcrop of welded tuff of this unit, as well as another of nonwelded tuff probably of this unit, have been found far south, approx 6 km south of Harris Mountain, near southwest edge of map area. Between welded outcrop south of Harris Mountain and caldera are several lava flows not overlain by this unit, which must have been deposited by pyroclastic flow southwest from caldera prior to emplacement of units mug, mdp, aeg, and others. Drill hole 62–21 on upper southwest flank of MLV begins in younger unit asr and intercepts unit dta at depth of approx 575 to 695 ft (175 to 212 m) below surface, indicating that considerable amount of this unit traveled southward (Donnelly-Nolan, 2006). Unit is variable in appearance, ranging in color from light gray and beige to red to brown and brownish black. Outcrops having darker colors typically are more welded and usually form thinner layer of tuff; no vitrophyre has been found in outcrop, but boulders of vitrophyre are present in gravel deposited by flood (for example, at Antelope Well). Where deposits are thicker and are cut by channels (for example, upstream from Antelope Well), typical exposure displays 1- to 2-m-high rounded walls. More commonly, unit is in reddish, flat tablets that are a meter or so wide and only 0.3 m or less thick. In many cases, blocks of tuff are scattered about in shallow depressions on surface of older units. Distribution of tuff typically is generalized on this map because of intermittent nature of outcrops; mapping and portraying each small outcrop area is not appropriate at scale of this map. Unit is significant in that it is impervious to water where it is welded and intact and thus provides water storage

(for example, at Dock Well, Antelope Well, and other water holes). Phenocrysts (pumice lumps): 1–3% 1–2 mm plag; <<1% opx+cpx. Unit overlies many units, some of which are as follows: on north flank, units aes, bea, mnl, anl, mbp, and dec, as well as older surficial unit og; east of caldera, units reg, rsl, and deg; within caldera, units awm and mbp; to west, units obw, mtf, mwr, and atm; and to south, unit obd. This unit underlies numerous units as well: to northwest and north, units mf, bts, bpw, bmc, and aib; to east, units bls, bt, bl, and aib; and caldera-rim lavas of units asr, anr, and drs. 40Ar/39Ar age is 171±43 ka (table 1), which correlates with marine oxygen-isotope records that indicate cooler time about 180,000 years ago (Martinson and others, 1987; Bassinot and others, 1994; Worm, 1997). Stratigraphic relation to other dated units, together with climate constraints, indicates that this unit must be between 180 and 185 ka and is more likely the former. The 180-ka age is used herein as likely age for unit. Sectors B, C, D, E, F, G, H, K, L. *GRI Source Map ID 7411.* (*Lava Beds NM*).

PEdls - Dacite east of Lost Spring (middle Pleistocene)

Sparsely porphyritic dacite (68.7% SiO2) flow that was erupted from small vent dome less than 1.5 km east-northeast of Lost Spring. Phenocrysts, 3%: 1–2 mm plag. Small (<2 cm) MI are scattered throughout rock, but none were large enough for analysis. Overlies units orr, mrl, afr, and bss; underlies unit bwd. K-Ar age is 182±4 ka (table 1). Sectors C, D. *GRI Source Map ID 7411.* (*Lava Beds NM*).

PEbst - Basalt southwest of Tickner Cave (middle Pleistocene)

Moderately porphyritic basalt (52.6, 53.0% SiO2) just south of LBNM, consisting mostly of large cinder cone and two outcrop areas of lava flow on lower northeast flank. Cinder cone is known locally as either “Berthas Butte” (for nearby Berthas Cupboard Cave) or “Railroad Butte” (for old railroad grade that wraps around cone). Phenocrysts, 3–5%: 1–4 mm plag; 1–2 mm ol; plag>ol; sparse 2–4 mm plag+ol clots. Underlies all adjacent units (asm, bmc, mna, bvc). Sectors I, J. *GRI Source Map ID 7411.* (*Lava Beds NM*).

PEmrc - Basaltic andesite of Red Cap Mountain (middle Pleistocene)

Variably porphyritic basaltic andesite (53.0, 53.6% SiO2) lava and cinder forms “red cap” on glaciated Red Cap Mountain; unit also has flows to east and west of crest. Three eroded vents have north-to-northeast alignments. More than one rock type is present: one is very porphyritic and tends to be found as large solid blocks and as cinders at vents; other is poorly to moderately porphyritic and is found as bombs, as smaller pieces of float rock, and as cinders at vent areas. Phenocrysts in porphyritic type: dominantly plag, approx 20%, 1–3mm; =1% ol; sparse 1 mm cpx. Phenocrysts in less porphyritic type: 1–5% 1–2 mm plag; =1% 1 mm ol; rare 1 mm cpx. Combination of factors, including glaciation, heavy mantle of pumice from late Holocene Little Glass Mountain eruption, extensive logging, and steep vegetation-covered slopes, has resulted in few real exposures and many float rocks, making mapping difficult. Overlies units orr, ods, oap, mnp, mwr, and bss; underlies unit dta. Sectors D, E. *GRI Source Map ID 7411.* (*Lava Beds NM*).

PEbsp - Basalt of Shotgun Peak (middle Pleistocene)

Variably porphyritic basalt (51.8–53.3% SiO2; avg of 4 = 52.6%) cinder cones aligned about N. 35° W.; no lava flows are visible. Shotgun Peak has glacial till on its north flank up to 6,500 ft (1,981 m) elevation, although till is not separately mapped. Cone immediately north of Burnt Lava Flow (unit abl) is

most porphyritic, showing approx 10% phenocrysts: mostly plag =5 mm; minor ol =2 mm. Shotgun Peak itself and two cones farther southeast that are entirely surrounded by Burnt Lava Flow contain 1–3% 1–4 mm plag; 1% 1–2 mm ol. All four cones are chemically similar. Underlies all adjacent units (msp, asr, abl). Sector M. *GRI Source Map ID 7411.* (*Lava Beds NM*).

PEdec - Dacite east of Callahan Flow (middle Pleistocene)

Sparsely porphyritic dacite (67.3, 70.2% SiO2) in two outcrop areas: one south, and another southeast, of southeast edge of late Holocene Callahan Flow (unit mcf). Vent location is unknown and presumably is to south. Significant northeast-trending fault zone, down to east, lies between two outcrop areas of this unit. Contains MI (55.0–57.8% SiO2). Phenocrysts, approx 3%: plag =3 mm; opx =2 mm; plag>opx. Overlies units rse, b8, and asc; underlies units dta, ama, mnm, anr, bmc, bec, and mcf. 40Ar/39Ar age is 200±2 ka (table 1); see also, Donnelly-Nolan and Lanphere (2005) for additional data. Sectors G, H, I. *GRI Source Map ID 7411.* (*Lava Beds NM*).

PEmtc - Basaltic andesite near Tickner Cave (middle Pleistocene)

Poorly porphyritic basaltic andesite (55.6% SiO2) lava flow and (mostly buried) cinder cone, found in one small, and another very small, outcrop area just south of LBNM. Phenocrysts: approx 1% 1–2 mm plag+ol; plag>ol. Underlies all adjacent units (aib, mna, bvc). Sector J. *GRI Source Map ID 7411.* (*Lava Beds NM*).

PEdeg - Dacite east of Glass Mountain (middle Pleistocene)

Porphyritic dacite (69.3% SiO2) flow directly east of Glass Mountain. Vent location is unknown but probably is buried under Glass Mountain lava (unit rgm). Phenocrysts: 5–7% 1–4 mm plag, commonly elongate; =1% 1 mm opx. Overlies units reg and beg; underlies units dta, aug, bl, aib, and rgm. K-Ar age is 203±6 ka (table 1). Sector L. *GRI Source Map ID 7411.* (*Lava Beds NM*).

PEmbp - Basaltic andesite of Badger Peak (middle Pleistocene)

Porphyritic basaltic andesite (54.4, 55.0% SiO2) that flowed northwest from several vents located at and near poorly defined northwest margin of caldera. Five vents, including Badger Peak and Grouse Hill, are scattered in area of about 3.5 km by 2 km; some cones lie on possible northeasterly trends. Unit has been glaciated, as described by C.A. Anderson (1941). Phenocrysts: approx 5% 1–3 mm plag; <1% 1 mm ol. Northwest of caldera, overlies units rcg, dsk, anl, and awh; underlies units dta, mfh, anr, and rlg. Within caldera, overlies units awm and dwm; underlies units dta, mug, and anr, as well as surficial units l and p. Sectors E, F, G. *GRI Source Map ID 7411.* (*Lava Beds NM*).

PEmc - Basaltic andesite south and southwest of Caldwell Butte (middle Pleistocene)

Sparsely porphyritic basaltic andesite (56.1% SiO2) lava flow and small cinder cone at south boundary of LBNM. Phenocrysts: 1–2% 1–2 mm plag+ol, plag>ol. Underlies units bci, aib, and bvc. Previously designated “unit a” by Donnelly-Nolan and Champion (1987). Sector J. *GRI Source Map ID 7411.* (*Lava*

Beds NM).

PEmnd - Basaltic andesite northeast of Doe Peak (middle Pleistocene)

Poorly porphyritic basaltic andesite (53.5% SiO2); vent unknown. Composition does not match that of nearby isolated cinder cones (units b12 and m18), either chemically or petrographically. Phenocrysts: <1% 1–3 mm plag; rare =1 mm ol. Overlies units rgf and b14; age relation to unit mwg is uncertain, but this unit is probably older. May overlie unit b12; underlies units mdp, bnp, and bsl. Sector C. *GRI Source Map ID 7411.* (*Lava Beds NM*).

PEa2 - Andesite of Red Butte (middle Pleistocene)

Moderately porphyritic andesite (59.1% SiO2) of Red Butte cinder cone in LBNM, southwest of monument headquarters. Cone consists of oxidized bombs and cinders and appears to be old morphologically, having no crater remaining. Phenocrysts: approx 5% plag, mostly 1–2 mm, some =4 mm; 1% 1 mm ol. Underlies surrounding unit bmc. Sector I. *GRI Source Map ID 7411.* (*Lava Beds NM*).

PEawh - Andesite west of Little Mount Hoffman (middle Pleistocene)

Porphyritic andesite and minor dacite (61.1–64.4% SiO2; avg of 4 = 62.5%) flow extending nearly 9 km to northwest from edge of Little Mount Hoffman. Vent location is unknown but probably is buried just north or northeast of Little Mount Hoffman. Unit contains numerous MI, two of which contain 57.9 and 59.2% SiO2. Phenocrysts: approx 5% 1–2 mm plag; 1% 1 mm cpx+opx; rare ol, in ol+pyx+plag clots; some xls are from disaggregated inclusions. Largest MI (12 cm across) are found at south end of unit, nearer to presumed vent location; north end of flow contains only =1 cm clots of xls. Overlies units ord, rcg, bea, mlh, and anl; underlies units mbp, dta, blh, bpw, anr, and rlg. Sectors D, E, F. *GRI Source Map ID 7411.* (*Lava Beds NM*).

PEbeg - Basalt east of Glass Mountain (middle Pleistocene)

Porphyritic basalt (51.0% SiO2) covering relatively small area east of Glass Mountain flow (unit rgm); vent unknown and probably buried beneath Glass Mountain lava. Phenocrysts, approx 10%: =2 mm plag+ol, plag>>ol; plag+ol also in 2–3 mm clots. Groundmass crowded with <1 mm plag+ol xls visible to naked eye, plag>>ol. Overlies unit reg; underlies units deg, bl, and rgm. Sector L. *GRI Source Map ID 7411.* (*Lava Beds NM*).

PEmph - Basaltic andesite of Powder Hill (middle Pleistocene)

Porphyritic basaltic andesite (53.4% SiO2) of Powder Hill cinder cone and also small area of lava flow exposed to southeast. Phenocrysts, approx 10%: 1–3 mm plag+ol; plag>ol. Underlies units bph and bgc. Sectors A, B. *GRI Source Map ID 7411.* (*Lava Beds NM*).

PEasc - Andesite from cone at southeast edge of Callahan Flow (middle Pleistocene)

Moderately porphyritic andesite (58.5, 59.0% SiO2) in five separate outcrop areas: cinder cone at southeast edge of Callahan Flow (unit mcf); isolated part of another cone that is entirely surrounded by Callahan Flow; and three outcrop areas of lava flow adjacent to southern tip of Callahan Flow. Phenocrysts, 5%: 1–3 mm plag; 1–2 mm pyx; plag>pyx. Overlies unit rse; underlies units dec, mnm, bsc, anr, and mcf. Sectors G, H. *GRI Source Map ID 7411.* (*Lava Beds NM*).

PEa4 - Andesite cone west of Cougar Butte (middle Pleistocene)

Sparsely porphyritic andesite (62.0% SiO2) cinder cone about 2 km west of Cougar Butte. Phenocrysts: approx 2% 1–2 mm plag. Probably underlies unit mni; underlies unit aib. Sector J. *GRI Source Map ID 7411.* (*Lava Beds NM*).

PEb12 - Basalt cone northeast of Doe Peak (middle Pleistocene)

Porphyritic basalt (52.6% SiO2) cinder cone approx 1.5 km northeast of Doe Peak. Phenocrysts: 5–10% 1–3 mm plag+ol, plag>ol. Probably overlies unit mnd; underlies units mdp and bnp. Sector C. *GRI Source Map ID 7411.* (*Lava Beds NM*).

PEa9 - Andesite cone southwest of Little Mount Hoffman (middle Pleistocene)

Very porphyritic andesite (58.0% SiO2) cinder cone partially buried by Little Glass Mountain rhyolite flow (unit rlg) and airfall tephra that preceded it. Phenocrysts (in solid blocks exposed in small quarry): approx 20% 1–2 mm, mostly plag; 1 mm ol+cpx+opx(?) constitute approx 5% of rock. Probably underlies adjacent unit mug; underlies units anr and rlg. Sector D. *GRI Source Map ID 7411.* (*Lava Beds NM*).

PEdac - Dacite in Aspen Crater (middle Pleistocene)

Porphyritic dacite (64.0% SiO2) from single outcrop exposed on north wall of Aspen Crater. Contains MI in range of sizes, from <1 cm to several centimeters; one was analyzed (55.5% SiO2). Phenocrysts are abundant and include xls from disaggregated MI. Phenocrysts, approx 10%: mostly plag, 1–2 mm; subordinate smaller ol. Underlies unit bac. Sector J. *GRI Source Map ID 7411.* (*Lava Beds NM*).

PEbsh - Basalt of Saddle Hills (middle Pleistocene)

Moderately porphyritic basalt (50.6% SiO2) of three cinder cones and one small area of lava flow southeast of Six Shooter Butte. Perhaps also scraped by south-southwest-moving ice. Two cones are aligned N. 30° E.; northernmost one is offset to west. Phenocrysts: approx 5%, mostly 1–3 mm plag; some 1 mm ol. Underlies units as and bgc. Sector A. *GRI Source Map ID 7411.* (*Lava Beds NM*).

PEmwd - Basaltic andesite west of Devils Homestead (middle Pleistocene)

Poorly porphyritic fine-grained basaltic andesite (52.6, 54.2% SiO2) lava that has scattered large tumuli. Vent(s) located to south is (are) are buried under younger lava flows. Phenocrysts: approx 1% =2 mm plag; sparse 1 mm ol xls. Overlies units ob and obg; underlies units dta, awf, and awb. Sector H. *GRI Source Map ID 7411.* (*Lava Beds NM*).

PEa8 - Andesite cone south of Little Mount Hoffman (middle Pleistocene)

Poorly porphyritic andesite (59.7% SiO2) cinder cone about 1 km south of Little Mount Hoffman and 1 km east of Little Glass Mountain. Phenocrysts, <1%: mostly 1 mm plag. Numerous small xenoliths. Underlies units mug, mel, and anr. Sector D. *GRI Source Map ID 7411.* (*Lava Beds NM*).

PEm19 - Basaltic andesite of Six Shooter Butte (middle Pleistocene)

Sparsely porphyritic basaltic andesite (53.9% SiO2) of large, eroded Six Shooter Butte cinder cone, approx 7 km south of Medicine Lake, just east of Giant Crater. Unusual elongate shape of cone suggests that it may have been glaciated. Phenocrysts: 1% 1 mm plag+ol+cpx xls, plag>ol+cpx. Underlies all adjacent units (as, asr, bgc). Sectors A, B. *GRI Source Map ID 7411.* (*Lava Beds NM*).

PEa7 - Andesite cone west of Crater Glass Flow (middle Pleistocene)

Poorly porphyritic andesite (57.2% SiO2) cinder cone approx 2 km west of Crater Glass Flow. Phenocrysts: <1% 1 mm plag; rare 4–5 mm plag. Contains sparse 3–5 mm, partially melted, vesiculated, silicic inclusions. Cone is surrounded by younger unit mbp; underlies unit dta. Sector F. *GRI Source Map ID 7411.* (*Lava Beds NM*).

PEb14 - Basalt cone east of Doe Peak (middle Pleistocene)

Moderately porphyritic basalt (52.3% SiO2) cinder cone less than 2 km east of Doe Peak. Phenocrysts small, >5%: mostly 1 mm plag, some ol. Underlies units mnd, mdp, and bsl. Sector C. *GRI Source Map ID 7411.* (*Lava Beds NM*).

PEa6 - Andesite cone southwest of Fourmile Hill (middle Pleistocene)

Poorly porphyritic andesite (57.6% SiO2) cinder cone approx 3 km southwest of Fourmile Hill and about 2.5 km north of Crater Glass Flow. Contains numerous small xenoliths. Phenocrysts: <1% 1 mm plag. Underlies units mbp and anr. Sector F. *GRI Source Map ID 7411.* (*Lava Beds NM*).

PEb13 - Basalt cone east of Six Shooter Butte (middle Pleistocene)

Sparsely porphyritic basalt (52.2% SiO2) cinder cone approx 2 km east of Six Shooter Butte. Phenocrysts: 1–2% 1–2 mm plag; sparse 1 mm ol xls. Underlies and is completely surrounded by unit as. Sector A. *GRI Source Map ID 7411.* (*Lava Beds NM*).

PEb15 - Basalt cone south of High Hole Crater (middle Pleistocene)

Porphyritic basalt (52.0% SiO2) cinder cone approx 2.5 km south of High Hole Crater within Burnt Lava Flow (unit abl). Phenocrysts: 5–10% 1–3 mm plag+ol, plag>ol. Completely surrounded by much younger unit abl. Sector M. *GRI Source Map ID 7411.* (*Lava Beds NM*).

PEanl - Andesite north of Little Glass Mountain (middle Pleistocene)

Poorly porphyritic andesite (8 samples, 58.0–60.2% SiO2; 1 sample, 63.0% SiO2; avg of 9 = 59.8%) exposed in several outcrop areas over an area of approx 6 km by 9 km on northwest flank of MLV. Vent is unknown but presumably is near northwest caldera rim. One area about 3 km west of Callahan Flow (unit mcf) is more porphyritic and has more rugged morphology than other outcrop areas, but it occupies similar stratigraphic position. Uppermost outcrop area has been glaciated, exposing interior dull-gray blocks and removing black glassy exterior blocks present in other outcrop areas. Phenocrysts: most samples have approx 1% plag =2 mm and a few 1 mm ol xls; sample from more porphyritic area has approx 2% of 1–3 mm plag and =1% of 1 mm ol. Contains granitic inclusions that display significant melting. Overlies units bea, mnl, bh, and mtr; underlies units mbp, dta, mfh, bpw, and anr. Sectors E, F, G. *GRI Source Map ID 7411.* (*Lava Beds NM*).

PEmsn - Basaltic andesite southwest of Snag Hill (middle Pleistocene)

Poorly porphyritic basaltic andesite (55.1% SiO2) lava flow forms several small kipukas west of Snag Hill andesite flow (unit asn). Phenocrysts: =1% 1 mm ol. Entirely surrounded by much younger unit bgc. Sector B. *GRI Source Map ID 7411.* (*Lava Beds NM*).

PEm18 - Basaltic andesite cone south of Paint Pot Crater (middle Pleistocene)

Porphyritic basaltic andesite (53.5% SiO2) cinder cone approx 3.5 km south of Paint Pot Crater, at south end of unit mpp. Phenocrysts, 10–15%: mostly 1 mm plag+ol, plag typically elongate, plag>ol; in addition, single 5 mm plag+ol+cpx clot present. Underlies units bsl and mpp; overlies unit rgf. Sector C. *GRI Source Map ID 7411.* (*Lava Beds NM*).

PEbss - Basalt south of Squaw Peak (middle Pleistocene)

Very porphyritic basalt (50.4–51.7% SiO2; avg of 3 = 51.2%) of one cinder cone immediately south of Squaw Peak and two other cones and accompanying lava flow on northeast end of Fisk Ridge. Phenocrysts: 15–25%, mostly 1–3 mm plag; a few percent 1–2 mm ol. Overlies units ods, orr, omf, msr, mwr, and atm; underlies units mrc, dls, and dta. Sector D. *GRI Source Map ID 7411.* (*Lava Beds NM*).

PEb11 - Basalt cone northeast of Six Shooter Butte (middle Pleistocene)

Poorly porphyritic basalt (52.1% SiO2) cinder cone approx 3.5 km northeast of Six Shooter Butte. Phenocrysts: approx 1% 1 mm plag+ol, plag>>ol. Underlies units as and asr. Sector A. *GRI Source*

Map ID 7411. (*Lava Beds NM*).

PEb17 - Basalt of Round Mountain (middle Pleistocene)

Moderately porphyritic basalt (51.7% SiO2) forming large cinder cone at Round Mountain. Lava flows, if present, are buried by the basalt of Yellowjacket Butte (byb) that surrounds cone. Phenocrysts, approx 5%: 1–3 mm plag; 1–2 mm ol; plag>ol. Underlies unit byb. Sector M. *GRI Source Map ID 7411.* (*Lava Beds NM*).

PEmtr - Basaltic andesite of “Tennant Road” (middle Pleistocene)

Moderately porphyritic basaltic andesite (55.3% SiO2) that was erupted from cinder cone approx 3 km southwest of Dock Well, south of road west to Tennant. Much of flow is mantled by unit dta. Phenocrysts: 2–3%, mostly 1 mm plag; plag+cpx+ol in clots; approx 1% 1 mm cpx+ol. Overlies units oap and bh; probably overlies unit b10; underlies units anl, dta, and bpw. Sectors E, F. *GRI Source Map ID 7411.* (*Lava Beds NM*).

PEbh - Basalt of Hill 22 (middle Pleistocene)

Sparsely porphyritic basalt (51.9% SiO2) that was erupted from cinder cone named Hill 22. Flow extends approx 1.5 km northwest of vent. Phenocrysts: 2–3% 1 mm ol+plag, ol>plag. Underlies units mtr, anl, and dta. Sector F. *GRI Source Map ID 7411.* (*Lava Beds NM*).

PEmlc - Basaltic andesite of Lava Crack Spring (middle Pleistocene)

Sparsely porphyritic basaltic andesite (53.2–57.0% SiO2; avg of 6 = 55.5%) flows and cone exposed on far south-southwest flank of MLV. North-northwest-trending major fault, which extends length of unit and beyond, bisects vent cone and offsets cone and lava flows down to east by at least 60 m. To east, a parallel but much shorter fault that has much less vertical offset also cuts unit and displaces it down to west. At least one additional vent to north must be buried by younger lava flows. Phenocrysts: 1–2% 1–3 mm plag; sparse 1 mm ol; rare plag+ol+cpx clots. One sample is slightly more porphyritic and has lowest silica content of samples collected. Overlies older diktytaxitic basalt of unit ob, which is interpreted to be pre-MLV in age; underlies units bwl, mug, and bgc, as well as surficial unit g. Sector B. *GRI Source Map ID 7411.* (*Lava Beds NM*).

PEb10 - Basalt cone southwest of Dock Well (middle Pleistocene)

Porphyritic basalt (52.7% SiO2) cinder cone, quarried, about 2.5 km southwest of Dock Well along major paved east-west road. Phenocrysts: 5–10% 1–3 mm ol+plag, ol>plag. Underlies unit dta; probably underlies unit mtr. Sectors E, F. *GRI Source Map ID 7411.* (*Lava Beds NM*).

PEb8 - Basalt cone east of Cinder Butte (middle Pleistocene)

Moderately porphyritic basalt (51.4% SiO2) cinder cone approx 2 km east of Cinder Butte at east edge of Callahan Flow (unit mcf). Phenocrysts: =5% 1–2 mm plag+ol, plag>ol. Underlies units dec, bmc, and mcf. Sector H. *GRI Source Map ID 7411.* (*Lava Beds NM*).

PEbet - Basalt east of Timber Hill (middle Pleistocene)

Porphyritic basalt (50.9, 51.0% SiO2) in four patches of mostly cindery material northeast of Porcupine Butte. Implied vent alignment is approx north-south. Phenocrysts: approx 5% 1–2 mm plag; 1–2% 1–2 mm ol; sparse plag+ol clots to =4 mm. Underlies units as and bgc. Sector A. *GRI Source Map ID 7411.* (*Lava Beds NM*).

PEmlh - Basaltic andesite of Little Mount Hoffman (middle Pleistocene)

Porphyritic basaltic andesite (55.7% SiO2) exposed on west flank of Little Mount Hoffman, under capping basaltic cinder cone of unit blh. Phenocrysts: 10–15% 1–2 mm plag; 1–2% 1–2 mm ol. Underlies units awh and blh. Sector E. *GRI Source Map ID 7411.* (*Lava Beds NM*).

PEb2 - Basalt cone at northeast edge of Sharp Mountain (middle Pleistocene)

Porphyritic basalt (51.1% SiO2) cinder cone west of Three Sisters (in northwestern part of map area), at northeast edge of Sharp Mountain. Phenocrysts: 5–10% 1–2 mm plag+ol, commonly in clots, plag=ol. Underlies unit bts. Sector F. *GRI Source Map ID 7411.* (*Lava Beds NM*).

PEdwm - Dacite west of Medicine Lake (middle Pleistocene)

Porphyritic dacite (67.9% SiO2) forming southeast side of glaciated hill that consists primarily of vent cone for unit mbp. Phenocrysts, as individual xls and as clots of xls, 10%: dominantly 1–3 mm plag; includes approx 2% 1 mm cpx+opx. Underlies units mug, mbp, and asr, as well as surficial unit p; probably overlies unit awm. Sector E. *GRI Source Map ID 7411.* (*Lava Beds NM*).

PEb3 - Basalt cone at east edge of Sharp Mountain (middle Pleistocene)

Poorly porphyritic basalt (51.5% SiO2) cinder cone between Sharp Mountain and Three Sisters (in northwestern part of map area). Phenocrysts: =1% 1 mm ol. Underlies units dta and bts. Sector F. *GRI Source Map ID 7411.* (*Lava Beds NM*).

PEbel - Basalt east of Lost Iron Well (middle Pleistocene)

Poorly porphyritic basalt (51.4% SiO2) occupying very small outcrop area about 3.5 km northeast of Harris Mountain. Phenocrysts rare: 1 mm plag+ol. Unit is exposed where it flowed against older unit rgf and where it was not completely buried by overlying unit mug. Sector B. *GRI Source Map ID 7411.* (*Lava Beds NM*).

PEawm - Andesite west of Medicine Lake (middle Pleistocene)

Very porphyritic andesite (59.1% SiO2). Unit is glaciated, but it has thick soil. East end of unit is hydrothermally altered; small landslide has taken place in this material. Phenocrysts, approx 30%: mostly 1–2 mm plag; includes 5% 1 mm cpx. Probably underlies unit dwm; underlies units mbp, dta, and mug, as well as surficial units p and l. Sectors E, F. *GRI Source Map ID 7411.* (*Lava Beds NM*).

PEb1 - Basalt of Hardin Butte (middle Pleistocene)

Very porphyritic basalt (52.1% SiO2) of Hardin Butte cinder cone, oxidized and partially buried, in central part of LBNM. Phenocrysts, 20–25%: 1–4 mm plag+ol, plag>ol; includes approx 5% 1–3 mm ol. Surrounded by the (younger) basalt of The Castles (bc); several vents of unit bc are located on lower west flank of Hardin Butte. Sector I. *GRI Source Map ID 7411.* (*Lava Beds NM*).

PErcg - Rhyolite west of Crater Glass Flow (middle Pleistocene)

Moderately porphyritic rhyolite (70.9% SiO2) in small outcrop area equidistant (approx 3.5 km) from west edge of Crater Glass Flow and from northern margin of Little Glass Mountain. Petrographic characteristics suggest possible correlation with downslope unit dsk, which has lower silica content than this unit. Phenocrysts: approx 5% 1–2 mm plag; minor =1 mm opx. Also contains =3 cm MI. Vitric groundmass typically is hydrated. Underlies adjacent units awh, mbp, and anr. Sector E. *GRI Source Map ID 7411.* (*Lava Beds NM*).

PEdsk - Dacite southwest of Kelley Pass (middle Pleistocene)

Moderately porphyritic, high-silica dacite (69.7, 70.2% SiO2) flow containing numerous andesitic and basaltic MI (51.3–57.4% SiO2). May correlate with unit rcg uphill to south; see also, unit ds for discussion of possible correlation with that unit. Phenocrysts: approx 5% 1–2 mm plag. Overlies unit bea; underlies units mbp, dta, and mfh. 40Ar/39Ar age of one MI is 244±20 ka (table 1), but this age may be too old; see discussion in unit ds description above. Sector F. *GRI Source Map ID 7411.* (*Lava Beds NM*).

PEbp - Basalt of Prisoners Rock (middle Pleistocene)

Clot-bearing basalt (48.0–49.5% SiO2; avg of 5 = 48.6%) that was erupted from north- and northeast-trending subaerial and subaqueous vents (including Prisoners Rock and The Peninsula), forming lava flows and spatter vents, in addition to tuff rings. Tuff rings were significantly eroded around west, north, and east sides by Tule Lake before lake was reclaimed for farmland beginning in the early 1900's. Well-exposed wave-cut benches can be seen along west and east sides. Phenocrysts (two lava flow samples): <1% 0.5–1 cm clots of plag+ol; 1% 1 mm ol. In addition, three samples of dikes exposed on eroded tuff rings display variable amounts of phenocrysts, and one sample is noticeably more porphyritic than lava flow samples. Unit lies beyond northeast margin of contiguous lavas of MLV. K-Ar age is 273 ±18 ka (table 1). See Donnelly-Nolan and Champion (1987), Lavine (1994), and Lavine and Aalto (2002) for additional description of unit. Sector J. *GRI Source Map ID 7411.* (*Lava Beds NM*).

PEdike - Dike (middle Pleistocene)

Dike rock found within the basalt of Prisoners Rocks (PEbp) above. Three samples of dikes exposed on eroded tuff rings display variable amounts of phenocrysts, and one sample is noticeably more porphyritic than lava flow samples. Lavine, A. (1994) indicates the dikes formed at about the same time as the basalt flows. No further unit description was provided. *GRI Source Map ID 7411.* (*Lava Beds NM*).

PEmnl - Basaltic andesite north of Lookout Butte (middle Pleistocene)

Sparsely porphyritic basaltic andesite (53.4–55.7% SiO2; avg of 4 = 54.1%) that was erupted from glaciated cinder cone approx 2.5 km southwest of Cinder Butte. Lava flow exists as several isolated outcrop areas on middle to lower northwest flank of MLV. Phenocrysts: 2–3% 1–3 mm plag; =1% 1–2 mm ol. Overlies units rgf, rwc, m4, bea, b7, aes, and arr; underlies units anl, dta, muc, mfh, anr, and mcf. 40Ar/39Ar age is 289±13 ka (table 1). Sectors F, G. *GRI Source Map ID 7411.* (*Lava Beds NM*).

PEb7 - Basalt cone southwest of Bonita Butte (middle Pleistocene)

Porphyritic basalt (50.4% SiO2) cinder cone approx 5 km southwest of Bonita Butte and approx 6 km northeast of Dock Well. Phenocrysts: 8–10% 1–3 mm plag; 1–2 mm ol; plag>>ol. Completely surrounded by younger unit mnl. Sector F. *GRI Source Map ID 7411.* (*Lava Beds NM*).

PEarr - Andesite of old railroad (middle Pleistocene)

Poorly porphyritic andesite (57.3% SiO2) lava flow of small outcrop area approx 3 km west of Cinder Butte. Vent unknown. Phenocrysts: 1% plag+ol; includes 1–3 mm plag, 1 mm ol. Underlies all adjacent units (mnl, dta, anr). Sector G. *GRI Source Map ID 7411.* (*Lava Beds NM*).

PEm17 - Basaltic andesite cone northeast of Cinder Cone (middle Pleistocene)

Sparsely porphyritic basaltic andesite (54.0% SiO2) cinder cone, mostly buried, approx 3 km north of Giant Crater. Phenocrysts, 2–3%: mostly 1 mm plag; <1% 1–2 mm ol. Underlies units mug and brh. Sector B. *GRI Source Map ID 7411.* (*Lava Beds NM*).

PEmj - Basaltic andesite of Juniper Butte (middle Pleistocene)

Basaltic andesite (53.8% SiO2) of eroded palagonite tuff ring in northeastern part of LBNM. Individual juvenile clasts are mud coated. Tuff ring probably formed by eruption through ancient Tule Lake. Unit is nearly surrounded by overlying unit bmc; remaining perimeter is overlain by unit bpa. Sector J. *GRI Source Map ID 7411.* (*Lava Beds NM*).

PEb16 - Basalt of Snell Butte (middle Pleistocene)

Porphyritic basalt (49.4% SiO2) of Snell Butte cinder cone, south of Burnt Lava Flow (unit abl); quarried. Extent of alteration and depth of soil suggest that cone is relatively old. Phenocrysts, =10%: 1–3 mm plag+ol, plag>ol. Underlies unit bdc, as well as later glacial-outwash gravel of surficial unit g. Sector M. *GRI Source Map ID 7411.* (*Lava Beds NM*).

PEbea - Basalt east of Antelope Well (middle Pleistocene)

Very porphyritic basalt (50.5% SiO2) exposed in numerous outcrop areas that are scattered low on northwest flank of MLV. Vent location is unknown but presumably is uphill to southeast. Phenocrysts: =15% 1–4 mm plag; 3–5% 1–2 mm ol. Overlies units ord and aes; underlies units dsk, mnl, anl, awh, dta, and mfh. Sectors F, G. *GRI Source Map ID 7411.* (*Lava Beds NM*).

PEmrr - Basaltic andesite of railroad (middle Pleistocene)

Moderately porphyritic basaltic andesite (54.4, 55.8% SiO2) on far south flank of MLV. Three vents aligned N. 25° W. are located south and southeast of Porcupine Butte. Vents have been downfaulted by about 100 m from easternmost extent of unit by northwest-trending fault. Phenocrysts: approx 3% plag =1 cm, typically elongate; <1% 1 mm ol. Overlies units bhi and bug; underlies units bnr, bdc, bpb, and byb. 40Ar/39Ar age is 251±6 ka (table 1). Sectors A, B. *GRI Source Map ID 7411.* (*Lava Beds NM*).

PEm4 - Basaltic andesite cone southwest of Cinder Butte (middle Pleistocene)

Moderately porphyritic basaltic andesite (53.9% SiO2) cinder cone about 3 km southwest of Cinder Butte. Phenocrysts, 5%: 1–2 mm, mostly plag; includes sparse 1 mm ol xls. Underlies units mnl and mfh. Sector G. *GRI Source Map ID 7411.* (*Lava Beds NM*).

PEm6 - Basaltic andesite cone northwest of Lookout Butte (middle Pleistocene)

Moderately porphyritic basaltic andesite (54.6% SiO2) cinder cone approx 1.5 km northwest of Lookout Butte, on northwest flank of MLV. Phenocrysts, <5%: mostly 1–2 mm plag; includes <1% 1 mm cpx+ol. Underlies surrounding unit mfh. Sector G. *GRI Source Map ID 7411.* (*Lava Beds NM*).

PEatm - Andesite of Typhoon Mesa (middle Pleistocene)

Nearly aphyric to sparsely porphyritic andesite (59.1–62.4% SiO2; avg of 8 = 60.4%) that probably was erupted under ice; present in several locations west of Little Glass Mountain. Typhoon Mesa, flat-topped tableland that has high, steep talus slopes, lies mostly west of map area. Isolated small conical hill, which probably represents inner core of a cinder cone, is present approx 0.5 km northwest of Tamarack Lake. About 1.5 km farther east is another such hill that includes large spindle bombs in coarse talus; this hill apparently vented lava flow that extends south and west of Squaw Peak and is now topographically higher than vent. Unit includes additional area to northeast, located between Pumice Stone Mountain and Tamarack Flat, that has same petrography and distinctive chemical composition; this area has topographic expression that suggests that andesite was constrained to flow north by ice

located to west. Unit also includes isolated lobe of andesite west of Squaw Peak that is petrographically very similar to other rocks of this unit but has higher silica content (62.0%). If any cinders of vent cones existed, they apparently have been removed by ice. Phenocrysts: <1% to 2% 1–2 mm plag; =1% 1–2 mm hb needles; rare 1 mm ol±pyx. Underlies units bss, dta, and bpw, as well as surficial units g and p; overlies units orr, ods, oap, mnp, aet, msr, mtf, mwr, mws, and mtl. K-Ar age is 254±25 ka (table 1) at Typhoon Mesa. 40Ar/39Ar age is 282±11 ka (table 1) at area southwest of Squaw Peak. Ages are compatible with time of global cooling (oxygen-isotope stage 8 of Martinson and others, 1987; see also, Shackleton and others, 1990; Bassinot and others, 1994; Worm, 1997; Herbert and others, 2001). Sectors D, E. *GRI Source Map ID 7411.* (*Lava Beds NM*).

PEm8 - Basaltic andesite cone northwest of Fourmile Hill (middle Pleistocene)

Poorly porphyritic basaltic andesite (54.0% SiO2) cinder cone approx 2 km northwest of Fourmile Hill. Phenocrysts, approx 1%: mostly 1 mm plag; rare 1 mm ol+cpx. Underlies surrounding unit mfh. Sector G. *GRI Source Map ID 7411.* (*Lava Beds NM*).

PEm15 - Basaltic andesite cone south of Little Glass Mountain (middle Pleistocene)

Nearly aphyric basaltic andesite (55.9% SiO2) cinder cone remnant approx 1 km south of south edge of Little Glass Mountain rhyolite flow (unit rlg). Phenocrysts: <<1% 1 mm plag+cpx, plag>cpx. Scattered xenoliths of andesite are present. Underlies units mug, aeg, and bsl. Sector C. *GRI Source Map ID 7411.* (*Lava Beds NM*).

PEmtl - Basaltic andesite of Tamarack Lake (middle Pleistocene)

Poorly porphyritic basaltic andesite (53.9–57.5% SiO2; avg of 7 = 56.1%). Glaciated vent-cone remnant is located at east edge of unit. Flow forms fairly large (2 × 3 km) flat surface east of Typhoon Mesa. Glacial gravel is present on flow surface, but it is not mapped. Phenocrysts: <1% 1 mm plag+ol, plag>ol. Overlies units aet, mwr, and mws; underlies unit atm and surficial unit p. Sectors D, E. *GRI Source Map ID 7411.* (*Lava Beds NM*).

PEafr - Andesite of Fisk Ridge (middle Pleistocene)

Very porphyritic andesite (60.8% SiO2), consisting of glaciated lava flow at northeast end of Fisk Ridge. Phenocrysts, approx 25%: mostly (more than half) 1–3 mm plag; also, in decreasing abundance, 1–2 mm opx, 1–5 mm hb needles, =1% cpx. Underlies unit dls; overlies units orr and mrl. Sectors C, D. *GRI Source Map ID 7411.* (*Lava Beds NM*).

PEmws - Basaltic andesite west of Squaw Peak (middle Pleistocene)

Sparsely porphyritic basaltic andesite (54.4% SiO2) cinder cone approx 1.5 km west of Squaw Peak. Phenocrysts: 1–2% 1 mm plag; sparse 1 mm ol. Smaller plag obvious in groundmass. Overlies unit mwr; underlies units mtl and atm, as well as surficial unit p. Sectors D, E. *GRI Source Map ID 7411.* (*Lava Beds NM*).

PEm13 - Basaltic andesite southwest of Kephart (middle Pleistocene)

Porphyritic basaltic andesite (55.1% SiO2). Probable eroded remnant of vent cone; surrounded by the (overlying) basalt of Tionesta (bt). Phenocrysts: 10–15%, mostly 2–4 mm plag; <1% 1 mm ol. Noticeable weathering rind on rocks suggests that unit may be pre-MLV in age. Sector L. *GRI Source Map ID 7411.* (*Lava Beds NM*).

PEmrl - Basaltic andesite of road to Lost Spring (middle Pleistocene)

Very porphyritic basaltic andesite (54.7% SiO2) exposed in small outcrop area approx 1.5 km east of Lost Spring. Phenocrysts, 30–40%: mostly 1–3 mm plag; includes approx 5% 1–2 mm pyx (opx+cpx), opx>>cpx. Overlies units orr and ael; underlies units afr, dls, and bwd. Sector C. *GRI Source Map ID 7411.* (*Lava Beds NM*).

PEael - Andesite east of Lost Spring (middle Pleistocene)

Very porphyritic andesite (60.4% SiO2) lava flow forming very small outcrop area approx 2 km east of Lost Spring. Vent unknown. Phenocrysts, 25–30%: mostly 1–2 mm plag, some larger. Rock contains approx 5% opx+cpx, opx>cpx. Underlies units mrl and bwd; overlies unit orr. Sector C. *GRI Source Map ID 7411.* (*Lava Beds NM*).

PEmwr - Basaltic andesite west of Red Cap Mountain (middle Pleistocene)

Poorly porphyritic and moderately porphyritic basaltic andesite (53.7–54.9% SiO2; avg of 7 = 54.6%) that was erupted from cinder cone approx 1.5 km south-southwest of Squaw Peak. Lower part of cone and lava flow northwest of Squaw Peak are poorly porphyritic; upper part of cone and some nearby lava flow are noticeably more porphyritic. However, rocks are very similar chemically, despite their petrographic variability. Phenocrysts in more porphyritic facies: 5–10% 1–3 mm plag; <1% 1–2 mm ol. Phenocrysts in less porphyritic rocks, =1%: =2 mm plag+ol, plag>ol. Overlies units orr, ods, msr, and mtf; probably overlies unit mnp; underlies units mws, mtl, atm, bss, mrc, and dta, as well as surficial unit p. 40Ar/39Ar age is 309±17 ka (table 1). Sectors D, E. *GRI Source Map ID 7411.* (*Lava Beds NM*).

PEaes - Andesite east of Six Shooter Pass (middle Pleistocene)

Poorly porphyritic andesite (58.3–60.7% SiO2; avg of 3 = 59.3%) exposed on lower northwest flank of MLV. Numerous patches are found over area of approx 10 km by 3 km. Vent unknown. Phenocrysts: 1% =2 mm plag; much smaller amount of 1 mm cpx. Overlies units ob, om, and oap; also in fault contact with older unit ob. Underlies units bea, mnl, dta, and bts, as well as surficial unit l (in this area, lake deposits of Bonita Lake basin). 40Ar/39Ar age is 307±24 ka (table 1). Sectors F, G. *GRI Source Map ID 7411.* (*Lava Beds NM*).

PEmsr - Basaltic andesite southwest of Red Cap Mountain (middle Pleistocene)

Poorly porphyritic basaltic andesite (53.3–53.9% SiO2; avg of 3 = 53.7%) cinder cone and lava flow. Cone is approx 1.5 km southwest of Red Cap Mountain and approx 4 km east of Typhoon Mesa. Phenocrysts, approx 1%: 1 mm plag; 1 mm ol; plag>>ol. Probably younger than unit bsr. Overlies unit orr; underlies units mwr, atm, bss, and dta. Sector D. *GRI Source Map ID 7411.* (*Lava Beds NM*).

PEmtf - Basaltic andesite of Tamarack Flat (middle Pleistocene)

Sparsely porphyritic basaltic andesite (56.2% SiO2) lava flow that bounds south edge of Tamarack Flat. Partially buried vent cone is at south end of flow. Phenocrysts: 1–2% 1 mm plag+ol. Abundant <1 mm plag in groundmass. Overlies unit oag; underlies units mwr, atm, and dta, as well as gravel of Tamarack Flat (surficial unit g). Sector E. *GRI Source Map ID 7411.* (*Lava Beds NM*).

PErec - Rhyolite east of Callahan Flow (middle Pleistocene)

Aphyric rhyolite (72.3–72.6% SiO2; avg of 3 = 72.5%) at southeast edge of Callahan Flow (unit mcf). Is faulted against, and also overlies, unit rse; also is faulted against stratigraphically younger unit bec; underlies units asc, bec, and mcf. Weighted average of two K-Ar ages is 322±22 ka (table 1). Sector H. *GRI Source Map ID 7411.* (*Lava Beds NM*).

PErsl - Rhyolite south of Little Sand Butte (middle Pleistocene)

Aphyric stony rhyolite (75.0% SiO2) and obsidian lava flow heavily mantled by pumice (not mapped) of Glass Mountain (unit rgm) eruption. Vent is unknown and presumably is located to southwest. Underlies units dta, bng, bt, bl, and aib, as well as surficial unit p; probably underlies unit bse. Weighted average of two K-Ar ages is 313±11 ka (table 1). Sector K. *GRI Source Map ID 7411.* (*Lava Beds NM*).

PEbsr - Basalt southwest of Red Cap Mountain (middle Pleistocene)

Very porphyritic basalt (51.3% SiO2) forming eroded (presumably glacially modified) cinder cone remnant on extension of ridge southwest of Red Cap Mountain. Phenocrysts, approx 25%: plag 1 mm to 1 cm, mostly 1–4 mm; 1–2 mm ol (approx 5% of rock); plag>>ol. Overlies unit orr; age relation to unit msr is uncertain, but this unit probably is older. Sector D. *GRI Source Map ID 7411.* (*Lava Beds NM*).

PErse - Rhyolite at southeast edge of Callahan Flow (middle Pleistocene)

Moderately porphyritic rhyolite (73.9–74.1% SiO2; avg of 3 = 74.0%) lava flow, commonly perlitic and (or) spherulitic, exposed in upfaulted block at southeast edge of Callahan Flow (unit mcf) and as spires protruding through overlying unit dec farther east. Phenocrysts, 5%: 1–3 mm plag, 1 mm opx, plag>opx. Underlies all adjacent units (rec, asc, dec, bec, mcf); faulted against stratigraphically younger units rec and mnm. K-Ar age is 330±40 ka (table 1; see also, Mertzman, 1982). Sectors H, I. *GRI Source Map ID 7411.* (*Lava Beds NM*).

PErwc - Rhyolite west of Callahan Flow (middle Pleistocene)

Aphyric rhyolitic (73.4% SiO2) obsidian exposed in small area west of upper Callahan Flow (unit mcf) and uphill from several exposures of unit rgf, which has different trace-element composition. Underlies unit mnl. K-Ar age is 349±7 ka (table 1). Sector G. *GRI Source Map ID 7411*. (Lava Beds NM).

PEaet - Andesite east of Typhoon Mesa (middle Pleistocene)

Porphyritic andesite (59.1% SiO2) cone at east edge of Typhoon Mesa andesite flow (unit atm). Phenocrysts, approx 10%: mostly 1–3 mm plag; includes approx 2% 1–2 mm opx. Underlies units mtl, atm, bss, and dta; overlies unit omf. Sector D. *GRI Source Map ID 7411.* (*Lava Beds NM*).

PErgf - Rhyolite of Grasshopper Flat (middle Pleistocene)

Aphyric or nearly aphyric rhyolite (75.2–75.7% SiO2; avg of 6 = 75.5%) exposed as kipukas, dominantly of obsidian, across nearly 30 km of west side of MLV. Outcrops west of Callahan Flow (unit mcf) are identical chemically to those south of Little Glass Mountain. If all these outcrops resulted from coeval eruptions, and if they represent highest parts of otherwise buried flows and domes, then north-northeast vent trend is suggested. Phenocrysts (sparse outcrops): <<1% 1 mm plag. Underlies all adjacent units. 40Ar/39Ar age is 387±6 ka (table 1; see also, Donnelly-Nolan and Lanphere, 2005). Sectors B, C, G. *GRI Source Map ID 7411.* (*Lava Beds NM*).

PEmnp - Basaltic andesite northwest of Paint Pot Crater (middle Pleistocene)

Very porphyritic basaltic andesite (55.1, 55.4% SiO2) that was erupted from two glaciated vents aligned N. 65° E., located about 2 km apart west of Little Glass Mountain. Phenocrysts, 20–25%: mostly 1–2 mm plag; 5% 1 mm ol; ol sometimes in clots =1 cm. Overlies units orr and oap; underlies units atm and mrc; probably underlies unit mwr. Sectors D, E. *GRI Source Map ID 7411.* (*Lava Beds NM*).

PErcb - Rhyolite near Cougar Butte (middle Pleistocene)

Aphyric rhyolite (77.2% SiO2), mostly stony but, in part, lithophysal and, in part, distinctive obsidian displaying scattered spherulites. Vent location is unknown although probably is buried by younger lavas not far to southwest of larger of two outcrop areas. Underlies all adjacent units (bco, bls, aib). 40Ar/39Ar age is 437±7 ka (table 1). Sector K. *GRI Source Map ID 7411.* (*Lava Beds NM*).

PEbug - Basalt under Giant Crater lava field (middle Pleistocene)

Aphyric, fine-grained, diktytaxitic basalt (49.3, 50.8% SiO2), found as patches extending nearly 20 km south and then southwest from its northernmost outcrop area west of Snag Hill. Large difference in Sr content of two samples suggests that unit may consist of two or more flows, which were erupted from multiple vents that presumably are buried north or northwest of Snag Hill. Probably younger than unit mhi. Underlies units mrr, bph, bwc, and bgc. 40Ar/39Ar age is 445±27 ka (table 1). Sectors A, B. *GRI Source Map ID 7411.* (*Lava Beds NM*).

PEbhp - Basalt of Hovey Point (middle Pleistocene)

Poorly porphyritic, diktytaxitic basalt (50.9% SiO2) at north edge of LBNM. Appears to have been inundated at some time by ancient Tule Lake. Phenocrysts: 0.5% 1 mm plag+ol, plag>ol. Underlies both adjacent units (bcb, bmc). 40Ar/39Ar age is 445±25 ka (table 1). See Donnelly-Nolan and Champion (1987) for additional description of unit. Sector I. *GRI Source Map ID 7411.* (*Lava Beds NM*).

PEreg - Rhyolite east of Glass Mountain (middle Pleistocene)

Aphyric rhyolite (two analyses, 76.4% SiO2) of older dome that has lost much of its original carapace of pumice and glass. Only exposed directly east of Glass Mountain, where young flows did not completely surmount older dome but instead deviated around to north and south. Underlies all adjacent units: beg, deg, dta, aug, bl, aib, and rgm. 40Ar/39Ar age is 475±29 ka (table 1). Sectors K, L. *GRI Source Map ID 7411.* (*Lava Beds NM*).

PEbhi - Basalt of Hambone Island (middle Pleistocene)

Aphyric, fine-grained diktytaxitic basalt (48.4% SiO2). Vent location unknown. Underlies all adjacent units (mrr, bwc, bgc). Broken by northwest-trending fault; may be older basalt flow underlying MLV. Sector A. *GRI Source Map ID 7411.* (*Lava Beds NM*).

PEobw - Older basalt of Garner Mountain (middle Pleistocene)

Moderately porphyritic basalt (two analyses, 51.7% SiO2) that was erupted from vents aligned approx N. 45° E., forming northeast ridge of Garner Mountain, edifice that lies just west of, and just predates, MLV. Lava extends to northeast and is found approx 2 km northwest of Hill 22. Phenocrysts, approx 5%: mostly 1 mm ol; includes some ol+plag clots and sparse 1 mm plag xls. Underlies units dta and bpw, as well as surficial unit g; overlies unit oap. Unit is undated; however, K-Ar ages of about 520 ka have been determined on other lavas from Garner Mountain (see description of unit oag). Sectors E, F. *GRI Source Map ID 7411.* (*Lava Beds NM*).

PEobd - Older basalt of Dry Lake (middle Pleistocene)

Aphyric, diktytaxitic basalt (48.5–49.4% SiO2; avg of 16 = 49.0%) at far southwest edge of MLV; unit also extends south of map area. Vent area located to west of MLV, as is most of unit (R.L. Christiansen and D.E. Champion, unpub. data, 2002). Unit is broken by north-trending faults, one of which displays offset down to west. Overlies units odh and ob; underlies units dta, bwl, mhm, and mdp, as well as surficial unit g. Sector B. *GRI Source Map ID 7411.* (*Lava Beds NM*).

PEopt - Older palagonite tuff (middle? Pleistocene)

Four separate outcrop areas of palagonite tuff, including Yellow Butte, which is a vent. All four areas are located low on north flank of MLV at margin of volcano; all probably predate MLV and likely represent eruptions through ancient lake. One analysis of vesicular clast from westernmost outcrop area is basaltic andesite (56.4% SiO2). Underlies adjacent units except om and ob. Sectors G, H. *GRI Source Map ID 7411.* (*Lava Beds NM*).

PEomf - Older basaltic andesite of Fisk Ridge (middle Pleistocene)

Sparsely porphyritic basaltic andesite consisting of one isolated cinder cone and at least one additional cinder cone to southwest outside map boundary. Phenocrysts: 1–2% 1 mm plag+ol. Abundant smaller plag xls in groundmass. Underlies adjacent units aet, bss, and dta. Probably predates MLV. Sector D. *GRI Source Map ID 7411.* (*Lava Beds NM*).

PEoag - Older andesite of Garner Mountain (middle Pleistocene)

Porphyritic to very porphyritic andesite (59.6% SiO2) lava exposed under lower east side of Garner Mountain, an edifice of significant size just west of MLV. Phenocrysts, 10–20%: dominantly plag, 1 mm to 1 cm; <1% 1 mm opx+cpx(?). Underlies all adjacent units: mtf and dta, as well as surficial unit g in Tamarack Flat. Unit is undated; however, K-Ar age on lava from west side of Garner Mountain is 520±30 ka (sample 78C4, Donnelly-Nolan and Lanphere, 2005); in addition, Brown and Mertzman (1979) listed K-Ar age of 520±210 ka for Garner Mountain lava (this unit). Sector E. *GRI Source Map ID 7411.* (*Lava Beds NM*).

PEomb - Older basaltic andesite of Black Mountain (middle Pleistocene)

Moderately porphyritic basaltic andesite (55.1% SiO2) forms large shield edifice southeast of caldera; unit is encompassed by lavas of MLV and is interpreted herein as predating MLV. Phenocrysts, 5%: 1–2 mm plag, 1 mm ol, plag>ol. Overlies unit obu; underlies unit bl and glacial-outwash gravel of surficial unit g. K-Ar age is 599±16 ka (table 1). Sectors L, M. *GRI Source Map ID 7411.* (*Lava Beds NM*).

PEoml - Older basaltic andesite of Lost Iron Well (middle or early Pleistocene)

Poorly porphyritic basaltic andesite (55.1% SiO2) exposed as isolated area of lava flow adjacent to Harris Mountain; outcrop displays thick red soil. Vent unknown. Phenocrysts: <1% 1–2 mm plag. Overlies unit odh; underlies units mhm and mdp. Interpreted herein as predating MLV. Sector B. *GRI Source Map ID 7411.* (*Lava Beds NM*).

PEobc - Older basalt of Casuse Mountain (middle or early Pleistocene)

Moderately porphyritic basalt (52.0% SiO2) of eroded cone of Casuse Mountain and its surrounding lava flow. Phenocrysts: 3–5% 1–2 mm plag; <1% 1 mm ol; rare =3 mm plag+ol+cpx clots. Probably overlies unit ob but predates MLV; underlies and is mostly surrounded by unit bmc. Sector J. *GRI Source Map ID 7411.* (*Lava Beds NM*).

PEog - Older gravel deposits (middle and early Pleistocene)

Well-rounded cobbles and pebbles. Mapped in one small and two very small areas in northwest corner of map; also exposed north of mapped area. Overlies unit otb; underlies unit dta and surficial unit g. Age is greater than 180 ka (age of unit dta) but less than 1.006±0.025 Ma (age of unit otb). Contains bluish

rhyolite cobbles and other rock types not recognizable as MLV lavas, indicating age is probably greater than about 500 ka. Sectors F, G. *GRI Source Map ID 7411.* (*Lava Beds NM*).

PEol - Older lake sediments (middle and early Pleistocene)

White, powdery lake sediments, much eroded, occupying low area south and southwest of Mount Dome. Sediments are at least in part younger than Mount Dome itself. Underlies units ob, otb, omb, dta, and bmc. Age is greater than about 500 ka. Sector G. *GRI Source Map ID 7411.* (*Lava Beds NM*).

PEoap - Older andesite of Pumice Stone Mountain (middle or early Pleistocene)

Porphyritic andesite (57.3–58.7% SiO2; avg of 6 = 57.7%) lava flow that has distinctive speckled appearance. Was erupted from Pumice Stone Mountain, as well as from probable second vent to northwest (now buried under unit mnp) and apparently from third vent on Wild Horse Mountain, about 14 km northwest of Pumice Stone Mountain. Vent alignment is approx N. 25° W. Lava flow traveled north at least 15 km from Pumice Stone Mountain and 6 km northeast of Wild Horse Mountain. Phenocrysts, 10–15%: 7–10% 1 mm plag; 2–5% ol+cpx+opx. Overlies unit orr; probably overlies domes of unit ord; underlies units obw, mnp, aes, atm, mtr, mrc, dta, bts, bpw, awl, and mpp, as well as surficial units g and l. K-Ar age is 949±29 ka (table 1). Sectors D, E, F. *GRI Source Map ID 7411.* (*Lava Beds NM*).

PEob - Older basalt (middle and early Pleistocene)

Typically aphyric or nearly aphyric basalt flows, commonly diktytaxitic in texture, exposed around margins of MLV. Many separate flows from different vents are represented in this lumped unit; all predate MLV, although ages of most are unknown, which is reason that this unit is not shown with asterisk added. However, one K-Ar age is 910±49 ka (table 1) for this unit near Gold Digger Pass, north of Callahan Flow (unit mcf). Sectors B, F, G, H, J, K, L. *GRI Source Map ID 7411.* (*Lava Beds NM*).

PEobu - Older basalt under Black Mountain (early Pleistocene)

Sparsely porphyritic basalt (52.8% SiO2) underlying east side of Black Mountain; also appears as patches under the Lake Basalt (bl) and the basalt of Tionesta (bt). Phenocrysts are clots a few millimeters across of ol+plag, in coarse-grained groundmass made up mostly of =1 mm plag and minor amounts of 1 mm ol. Underlies all adjacent units: omb, bt, and bl, as well as glacial-outwash gravel of surficial unit g. Sectors L, M. *GRI Source Map ID 7411.* (*Lava Beds NM*).

PEorr - Older rhyolite of Red Cap Mountain (early Pleistocene)

Moderately porphyritic rhyolite (73.6% SiO2) forming bulk of Red Cap Mountain west of Little Glass Mountain, although “red cap” is formed by overlying unit mrc. Predates MLV. Exposed in three outcrop areas that extend approx 5 km north-south and slightly less than 5 km east-west. Greatest exposed thickness exceeds 350 m. Probable vents for this glaciated unit are indicated at high points to south-southwest of Red Cap Mountain proper and approx 1.5 km to north. Phenocrysts, 5%: dominantly 1 mm plag, some to 2 mm; 1% 1 mm hb (needles) + opx (xls), hb>opx. Rock also contains small hb-bearing

MI typically a few millimeters to 1 cm across; one plutonic-textured xenolith also was observed. Underlies all adjacent units (oap, mnp, bsr, msr, ael, mwr, mrl, afr, atm, bss, mrc, dls, dta, bwd, bnp, and bsl). All nearby units are much younger than this unit, except for unit oap, which is only slightly younger. K-Ar age is 965±24 ka (table 1). Sectors C, D, E. *GRI Source Map ID 7411.* (*Lava Beds NM*).

PEord - Older rhyolite near Dock Well (early Pleistocene)

Moderately porphyritic older rhyolite (71.1, 72.3% SiO2) domes forming two kipukas on northwest flank of MLV. Total exposed area is about 2 km2. The dacite tuff of Antelope Well (dta) flowed part way up, and welded onto, caldera-facing (southeast) sides of both domes. Phenocrysts: 3–5% 1–3 mm plag; approx 1% 1 mm cpx+opx. Underlies units bea, awh, and dta; probably underlies unit oap. Four K-Ar age determinations on single sample of smaller dome range in age from 814±46 to 959±73 ka (Donnelly-Nolan and Lanphere, 2005); weighted mean average is 840±51 ka (table 1). In addition, Mertzman (1982) gave whole-rock K-Ar ages of 1.18±0.06 Ma, for larger dome, and 0.95±0.14 Ma, for smaller dome. Sector F. *GRI Source Map ID 7411.* (*Lava Beds NM*).

PEobp - Older basalt on west side of Gillem Fault (early Pleistocene)

Very porphyritic basalt (52.2% SiO2) in three small patches overlying Pliocene basalt (unit obg) that caps much of Gillem Bluff. Vent location unknown. Phenocrysts, approx 30%: dominantly plag, 1–4 mm; includes 2–3% 1–3 mm ol; scattered larger plag+ol clots. Overlies unit obg; underlies unit awf. Paleomagnetic data (D.E. Champion, written commun., 2005) indicates that unit has reversed polarity. See “unit pb” in Donnelly-Nolan and Champion (1987). Sector H. *GRI Source Map ID 7411.* (*Lava Beds NM*).

PEods - Older dacite of Squaw Peak (early? Pleistocene)

Poorly porphyritic dacite (67.1% SiO2) of glaciated dome that is largely surrounded by deposits of talus, most of which consists of pinkish, oxidized dacite. At base of western talus deposit is well-developed protalus rampart. Phenocrysts: <1% 1 mm plag. Underlies all adjacent units (mwr, atm, bss, mrc). Unit is aligned with domes of unit ord and may be similar in age to them and (or) to units orr and oap. Interpreted as older than MLV. Sectors D, E. *GRI Source Map ID 7411.* (*Lava Beds NM*).

PEotb - Older tuff of Box Canyon (early Pleistocene)

Rhyolitic ash-flow tuff (five pumice lumps, 68.9–71.2% SiO2; avg of 5 = 70.4%; one whole-rock analysis, 69.3% SiO2) near Box Canyon south of Mount Dome. Partially welded to nonwelded, pink-to-white ash-flow tuff as much as 10 m thick containing pinkish pumice lumps as large as 0.5 m in maximum dimension. Vent location unknown. Unit is broken by numerous faults that have varying trends and offsets. Phenocrysts (pumice lumps): approx 1% 1–2 mm plag; <1% 1 mm opx. Overlies surficial unit ol; interbedded with basalt of unit ob; underlies units aes, dta, aut, and bts, as well as surficial units og and g. 40Ar/39Ar age on plag is 1.006±0.025 Ma (table 1). Sectors F, G, H. *GRI Source Map ID 7411.* (*Lava Beds NM*).

PEom - Older basaltic andesite of Bonita Butte (early Pleistocene)

Porphyritic basaltic andesite (53.0% SiO2) lava and large vent cone of Bonita Butte. Phenocrysts: 10% 1–2 mm plag+ol, plag>ol. Most porphyritic lava is found at, and just north of, Bonita Butte. Underlies units ob, opt, aes, dta, bmc, and bgd, as well as surficial unit l. Predates MLV. K-Ar age is 1.211±0.067 Ma (table 1). Sector G. *GRI Source Map ID 7411.* (*Lava Beds NM*).

PLomt - Older basaltic andesite of Timber Mountain (late Pliocene)

Aphyric basaltic andesite (53.4% SiO2) of large, older, faulted shield that is surrounded by the basalt of Tionesta (bt) on lower east side of MLV. K-Ar age is 1.820±0.042 Ma (table 1). Sectors K, L. *GRI Source Map ID 7411.* (*Lava Beds NM*).

PLotg - Older tuff of Gillem Bluff (Pliocene)

Dacitic ash-flow tuff (six pumice lumps, 66.9–69.3% SiO2; avg of 6 = 68.0%; one whole-rock analysis, 66.9% SiO2) exposed in four closely spaced outcrop areas, each a few meters thick, at top of Gillem Bluff. Tuff is welded and typically is reddish. Phenocrysts: 1% 1–3 mm plag; 1 mm opx, plag>opx. Overlies units omw, obg, and omg. 40Ar/39Ar age on plag is 2.023±0.020 Ma (table 1). Sector H. *GRI Source Map ID 7411.* (*Lava Beds NM*).

PLomg - Older basaltic andesite of Gillem Bluff (Pliocene)

Nearly aphyric basaltic andesite (56.9% SiO2) lava flow remnants on Gillem Bluff. Phenocrysts: <1% 1 mm plag+ol. Overlies unit obg; underlies unit otg. See Donnelly-Nolan and Champion (1987) for additional information about this unit. Sector H. *GRI Source Map ID 7411.* (*Lava Beds NM*).

PLobg - Older basalt of Gillem Bluff (Pliocene)

Aphyric, diktytaxitic basalt (47.7, 47.9% SiO2) flow forming rimrock that caps upthrown fault block of Gillem Fault. Unit also includes pillow lavas exposed in Gillem Bluff in northernmost LBNM. Overlies unit omw, exposed by fault; underlies units omg, otg, bwg, mwd, dta, awf, and awb; may correlate with part of unit ob. Corresponds to “unit bgb” of Donnelly-Nolan and Champion (1987). Sector H. *GRI Source Map ID 7411.* (*Lava Beds NM*).

PLomw - Older basaltic andesite in western Lava Beds National Monument (Pliocene)

Sparsely to moderately porphyritic basaltic andesite (53.7% SiO2) exposed in face of Gillem Bluff. Phenocrysts: 2–5% 1–2 mm plag; minor =1 mm ol. Rock has speckled appearance. Underlies unit obg. Sector H. *GRI Source Map ID 7411.* (*Lava Beds NM*).

PLodh - Older dacite of Harris Mountain (Pliocene)

Porphyritic dacite (63.2, 63.9% SiO2) of large eroded dome and small dome to northwest that are encompassed by MLV lavas at southwest edge of volcano. Unit is broken by north-trending fault. Phenocrysts: approx 15% 1–5+ mm plag; approx 2% 1–3 mm altered hb; rare 1 mm cpx. Contains rare <3 mm plutonic-textured inclusions. Underlies all adjacent units (oml, obd, mhm, mdp). K-Ar age is 2.95 ±0.09 Ma (table 1). Sectors B, C. *GRI Source Map ID 7411.* (*Lava Beds NM*).

Units associated only with Geologic Sample Localities

Qagm - Andesite near Garner Mountain (Quaternary)

No further unit description provided. Unit found only in Geologic Sample Locations (LABEGSL) feature class. Geologic Symbol was generated from lithology and radiometric age provided in Table 1 of source. *GRI Source Map ID 75220* (for additional information see the GRI Digital Maps Citations page).

Qrdh_57-13 - Rhyolite at 1459' in drill hole 57-13 (Quaternary)

No further unit description provided. Unit found only in Geologic Sample Locations (LABEGSL) feature class. Geologic Symbol was generated from lithology and radiometric age provided in Table 1 of source. *GRI Source Map ID 75220* (for additional information see the GRI Digital Maps Citations page).

Qrdh_68-16 - Rhyolite at 1673' in drill hole 68-16 (Quaternary)

No further unit description provided. Unit found only in Geologic Sample Locations (LABEGSL) feature class. Geologic Symbol was generated from lithology and radiometric age provided in Table 1 of source. *GRI Source Map ID 75220* (for additional information see the GRI Digital Maps Citations page).

Qbpr - Basalt of Plum Ridge (Quaternary)

No further unit description provided. Unit found only in Geologic Sample Locations (LABEGSL) feature class. Geologic Symbol was generated from lithology and radiometric age provided in Table 1 of source. *GRI Source Map ID 75220* (for additional information see the GRI Digital Maps Citations page).

Qbh5160 - Basalt of Hill 5160 (Quaternary)

No further unit description provided. Unit found only in Geologic Sample Locations (LABEGSL) feature class. Geologic Symbol was generated from lithology and radiometric age provided in Table 1 of source. *GRI Source Map ID 75220* (for additional information see the GRI Digital Maps Citations page).

Qrbc - Rhyolite tuff of Box Canyon (Quaternary)

No further unit description provided. Unit found only in Geologic Sample Locations (LABEGSL) feature class. Geologic Symbol was generated from lithology and radiometric age provided in Table 1 of source.

GRI Source Map ID 75220 (for additional information see the GRI Digital Maps Citations page).

Qblpb - Basalt of Lone Pine Butte (Quaternary)

No further unit description provided. Unit found only in Geologic Sample Locations (LABEGSL) feature class. Geologic Symbol was generated from lithology and radiometric age provided in Table 1 of source. *GRI Source Map ID 75220* (for additional information see the GRI Digital Maps Citations page).

Qbcbl - Basalt of Chalk Bank Landing (Quaternary)

No further unit description provided. Unit found only in Geologic Sample Locations (LABEGSL) feature class. Geologic Symbol was generated from lithology and radiometric age provided in Table 1 of source. *GRI Source Map ID 75220* (for additional information see the GRI Digital Maps Citations page).

Qdclr - Basalt south of Clear Lake Reservoir (Quaternary)

No further unit description provided. Unit found only in Geologic Sample Locations (LABEGSL) feature class. Geologic Symbol was generated from lithology and radiometric age provided in Table 1 of source. *GRI Source Map ID 75220* (for additional information see the GRI Digital Maps Citations page).

Qbkb - Basalt of Knobcone Butte (Quaternary)

No further unit description provided. Unit found only in Geologic Sample Locations (LABEGSL) feature class. Geologic Symbol was generated from lithology and radiometric age provided in Table 1 of source. *GRI Source Map ID 75220* (for additional information see the GRI Digital Maps Citations page).

Qadhm - Andesite N.W. of Double Head Mountain (Quaternary)

No further unit description provided. Unit found only in Geologic Sample Locations (LABEGSL) feature class. Geologic Symbol was generated from lithology and radiometric age provided in Table 1 of source. *GRI Source Map ID 75220* (for additional information see the GRI Digital Maps Citations page).

Qdgb - Dacite tuff of Gillem Bluff (Quaternary)

No further unit description provided. Unit found only in Geologic Sample Locations (LABEGSL) feature class. Geologic Symbol was generated from lithology and radiometric age provided in Table 1 of source. *GRI Source Map ID 75220* (for additional information see the GRI Digital Maps Citations page).

Tmhjb - Basaltic andesite of Harvey Jones Butte (Tertiary)

No further unit description provided. Unit found only in Geologic Sample Locations (LABEGSL) feature class. Geologic Symbol was generated from lithology and radiometric age provided in Table 1 of source. *GRI Source Map ID 75220* (for additional information see the GRI Digital Maps Citations page).

Tmwf - Basaltic andesite dike near Winema Farms (Tertiary)

No further unit description provided. Unit found only in Geologic Sample Locations (LABEGSL) feature class. Geologic Symbol was generated from lithology and radiometric age provided in Table 1 of source. *GRI Source Map ID 75220* (for additional information see the GRI Digital Maps Citations page).

Tbhr - Basalt of High Rim (Tertiary)

No further unit description provided. Unit found only in Geologic Sample Locations (LABEGSL) feature class. Geologic Symbol was generated from lithology and radiometric age provided in Table 1 of source. *GRI Source Map ID 75220* (for additional information see the GRI Digital Maps Citations page).

Tdcl - Dacite of the Clear Lake Hills (Tertiary)

No further unit description provided. Unit found only in Geologic Sample Locations (LABEGSL) feature class. Geologic Symbol was generated from lithology and radiometric age provided in Table 1 of source. *GRI Source Map ID 75220* (for additional information see the GRI Digital Maps Citations page).

unk - Unit unknown (NA)

No further unit description provided. Features with an unknown geologic unit only found in the Geologic Sample Locations (LABEGSL) feature class. *GRI Source Map ID 75220* (for additional information see the GRI Digital Maps Citations page).

Medicine Lake Volcano and Lava Beds National Monument

Donnelly-Nolan, J.M., 2010, Geologic Map of Medicine Lake Volcano, Northern California, U.S. Geological Survey, Scientific Investigations Map SIM-2927, 1:50,000 scale. (*GRI Source Map ID 7411*).

The complete U.S. Geological Survey publication is available on web page: http://pubs.usgs.gov/sim/2927/

U.S. Geological Survey Spatial Database:

Ramsey, D.W., Felger, T.J., Lougee, Ellen, Bruggman, P.E., and Donnelly-Nolan, J.M., 2010, Database for the Geologic Map of Medicine Lake Volcano, Northern California, in Donnelly-Nolan, J.M., Geologic Map of Medicine Lake Volcano, Northern California, U.S. Geological Survey, Scientific Investigations Map SIM-2927 [CD-ROM].

The U.S. Geological Survey spatial database used to accompany Scientific Investigation Map SIM-2927 and additional photographs of Medicine Lake volcano are on web page; http://pubs.usgs.gov/sim/2927/sim2927_data/index.html

Unit Correlation

Unit correlation diagram is available as a sperate PDF document (Correlation of Map Units)

Extracted from: (*Lava Beds NM*).

Shaded Relief Map and Place Names

Shaded-relief map showing place names is available as a separate PDF download (Shaded Relief)

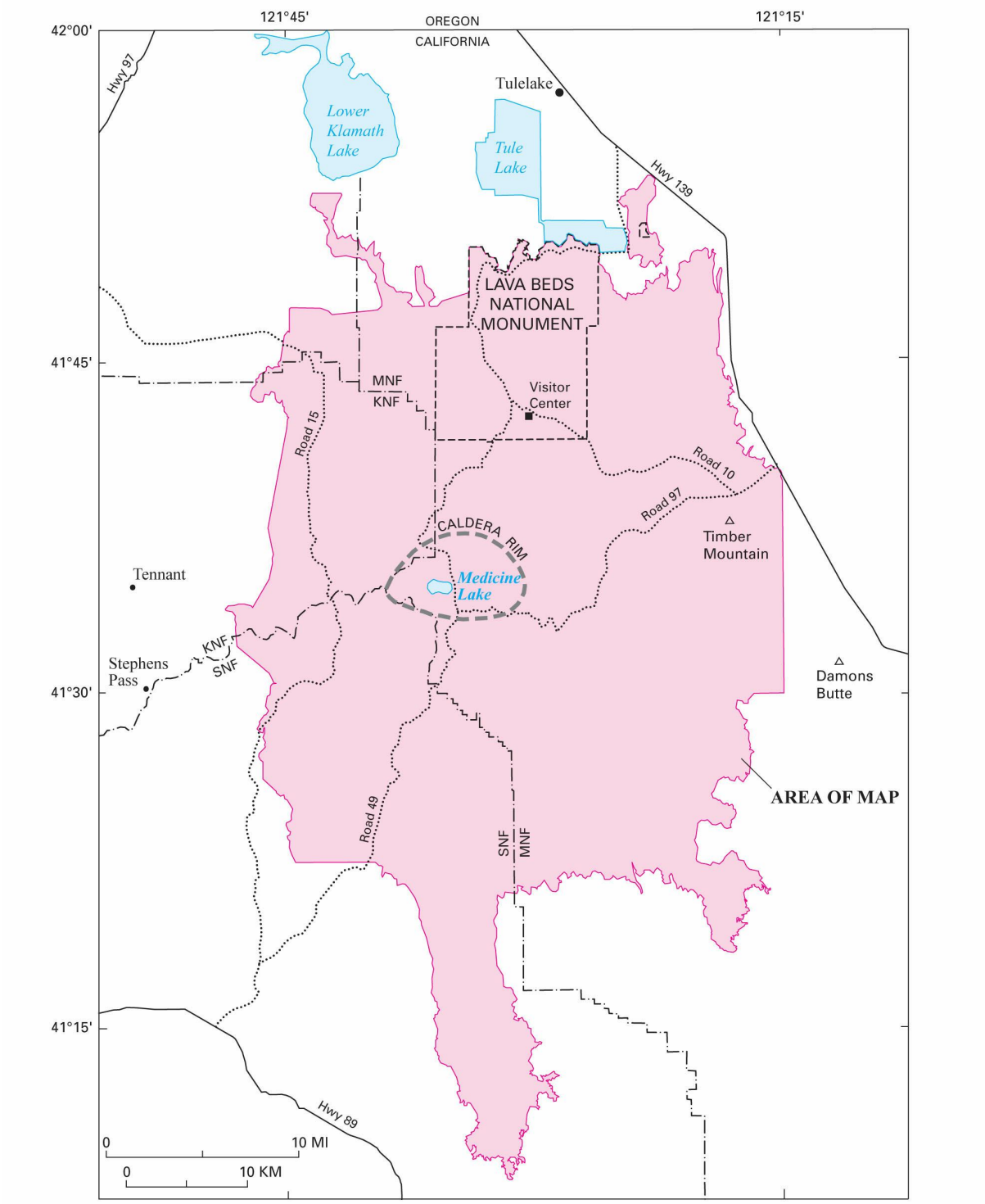
Extracted from: (*Lava Beds NM*).

Sector Location Map

The source authors divided the mapped area into 13 sectors radiating form a center at Medicine Lake. The sectors are used to locate units on the map and are referred to in the Unit Descriptions section and the text. Approximate azimuths of sector boundaries are shown at end of each sector boundary line (dot near center of Medicine Lake is starting point for each azimuthal direction). Sector letters indicate location of unit on map in “List of Map Units” and correspond to columns in “Correlation of Map Units.” Sector location map is available as a sperate PDF document (Sector Location Map)

Extracted from: (*Lava Beds NM*).

Index Map

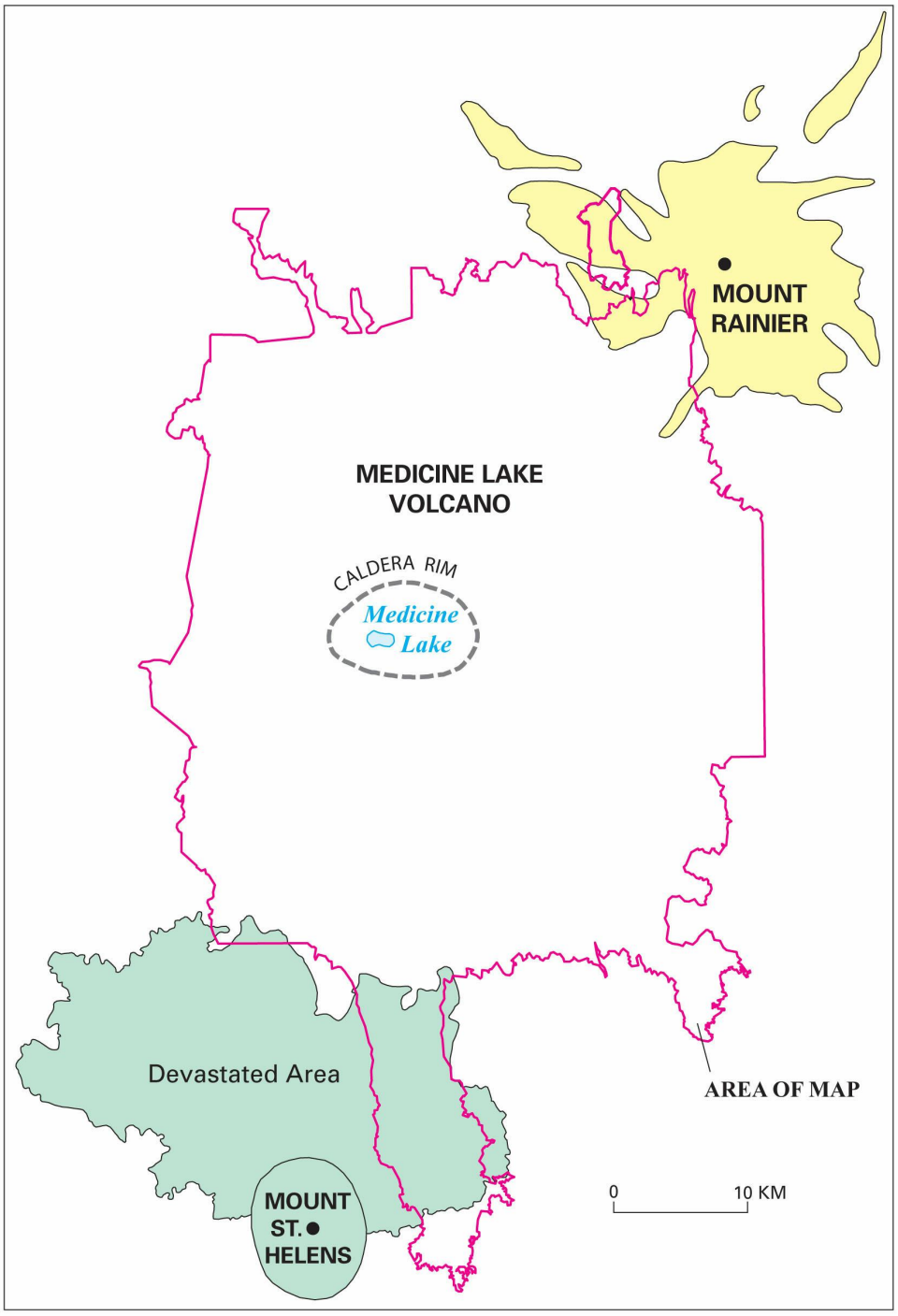


Location map showing major roads and land management boundaries on and near medicine Lake volcano. Magenta shading indicates area of geologic map. Major highways are depicted with solid black lines; dotted lines indicate significant secondary roads. National Forests: MNF, Modoc National Forest; SNF, Shasta-Trinity National Forest; and KNF, Klamath National Forest. Lava Beds National Monument

is administered by National Park Service. Town of Tulelake (about 1,000 residents) is largest population center within area. Boundary between California and Oregon is at top of map.

Extracted from: (*Lava Beds NM*).

Volcano Relative Size

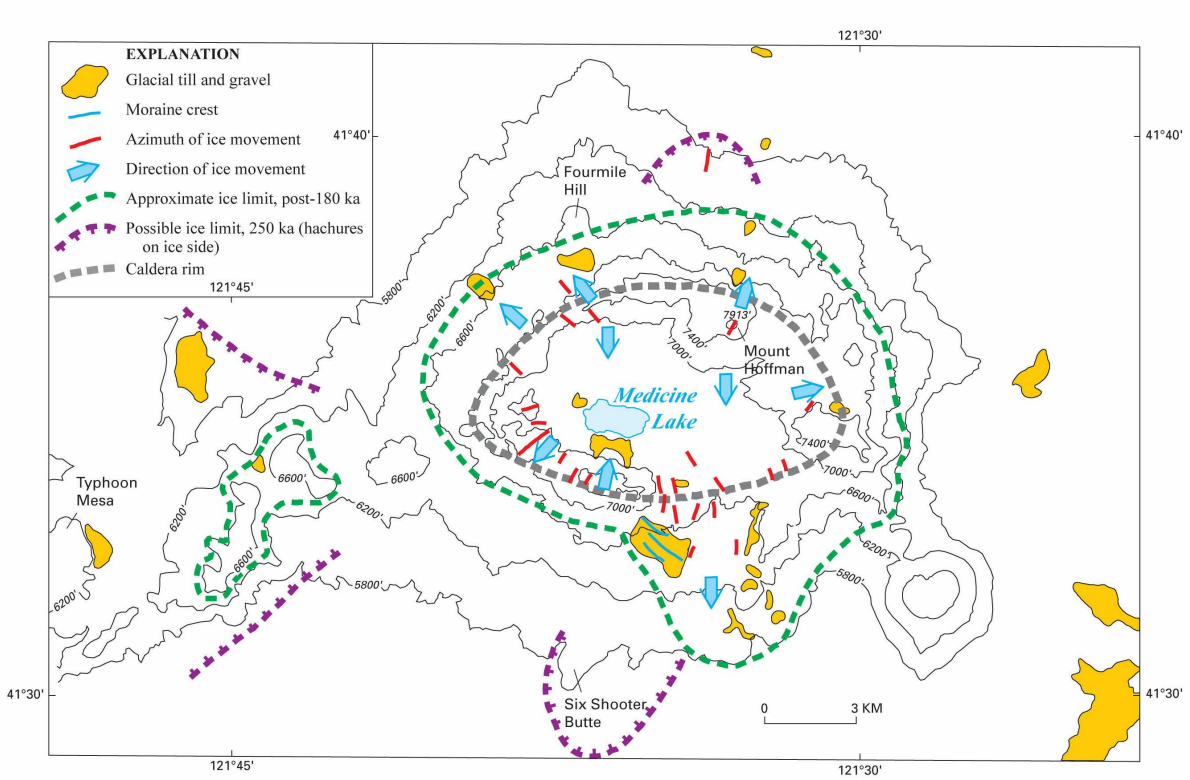


Sketch map showing area of Medicine Lake volcano (magenta outline) superimposed on areas of two volcanoes in southern Washington State Cascade Range, Mount St. Helens (green shading) and Mount Rainier (yellow shading), which are shown in their correct spatial positions with respect to each other and at same scale as Medicine Lake volcano. "Devastated Area" is area impacted by May 18, 1980

eruption of Mount St. Helens.

Extracted from: (*Lava Beds NM*).

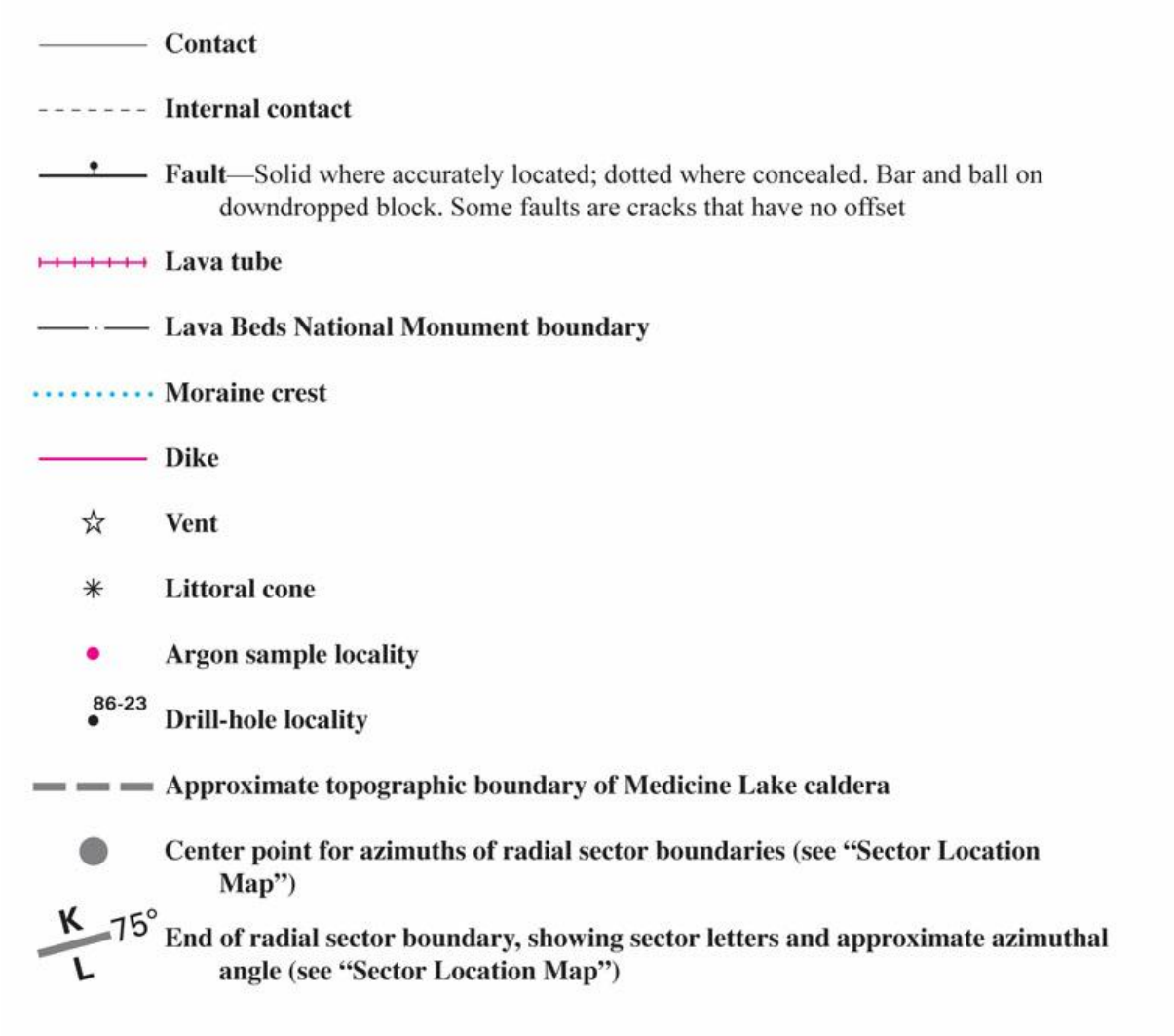
Ice Related Deposits



Map showing distribution of ice-related deposits, direction and azimuth of ice movement (in part based on glacial striations), and probable ice limits at various times during history of Medicine Lake volcano. Ice apparently moved away from caldera, but it also accumulated within caldera and flowed out lowest (southeast) side, leaving striations and morainal deposits of gravel. Morainal ridges are present in large area of till approximately 3 km south-southeast of Medicine Lake.

Extracted from: (*Lava Beds NM*).

Map Legend



Extracted from: (*Lava Beds NM*).

Report Pamphlet

The USGS report pamphlet is available as a separate PDF document (SIM-22927 Pamphlet).

Extracted from: (*Lava Beds NM*)..

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