Compilation of Stratigraphic Thicknesses for Caldera-Related Tertiary Volcanic Rocks, East-Central Nevada and West-Central Utah

Data Series 271

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

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By D.S. Sweetkind and E.A. du Bray

Prepared in cooperation with the Bureau of Land Management

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Conversion Factors

Multiply	By	To obtain
inch	2.54	centimeter (cm)
inch	25.4	millimeter (mm)
foot (ft)	0.3048	meter (m)
mile (mi)	1.609	kilometer (km)
centimeter (cm)	0.3937	inch (in.)
millimeter (mm)	0.03937	inch (in.)
meter (m)	3.281	foot (ft)
kilometer (km)	0.6214	mile (mi)

Horizontal coordinate information is referenced to the North American Datum of 1983 (NAD 83).

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By D.S. Sweetkind and E.A. du Bray

Abstract

The U.S. Geological Survey (USGS), the Desert Research Institute (DRI), and a designee from the State of Utah are currently conducting a water-resources study of aquifers in White Pine County, Nevada, and adjacent areas in Nevada and Utah, in response to concerns about water availability and limited geohydrologic information relevant to ground-water flow in the region. Production of ground water in this region could impact water accumulations in three general types of aquifer materials: consolidated Paleozoic carbonate bedrock, and basin-filling Cenozoic volcanic rocks and unconsolidated Quaternary sediments. At present, the full impact of extracting ground water from any or all of these potential valley-graben reservoirs is not fully understood. A thorough understanding of intermontane basin stratigraphy, mostly concealed by the youngest unconsolidated deposits that blanket the surface in these valleys, is critical to an understanding of the regional hydrology in this area. This report presents a literature-based compilation of geologic data, especially thicknesses and lithologic characteristics, for Tertiary volcanic rocks that are presumably present in the subsurface of the intermontane valleys, which are prominent features of this area.

Two methods are used to estimate volcanic-rock thickness beneath valleys: (1) published geologic maps and accompanying descriptions of map units were used to compile the aggregate thicknesses of Tertiary stratigraphic units present in each mountain range within the study areas, and then interpolated to infer volcanic-rock thickness in the intervening valley, and (2) published isopach maps for individual outflow ash-flow tuff were converted to digital spatial data and thickness was added together to produce a regional thickness map that aggregates thickness of the individual units. The two methods yield generally similar results and are similar to volcanic-rock thickness observed in a limited number of oil and gas exploration drill holes in the region, although local geologic complexity and the inherent assumptions in both methods allow only general comparison. These methods serve the needs of regional ground-water studies that require a three-dimensional depiction of the extent and thickness of subsurface geologic units. The compilation of geologic data from published maps and reports provides a general understanding of the distribution and thickness of tuffs that are presumably present in the subsurface of the intermontane valleys and are critical to understanding the ground-water hydrology of this area.

Introduction

As populations in the southwestern United States continued to increase through the 1990s and 2000s, reliance on water from the Colorado River basin has become increasingly important. To decrease their dependence on this limited surface-water resource, water purveyors in southern Nevada have proposed to use the ground-water resources of rural basins in eastern and central Nevada to help provide for the projected increase in population and associated water supply issues in the Las Vegas area. Most of these basins historically (prior to 2006) have pumped limited quantities of ground water, typically less than 20,000 acre-ft per year. As a result, municipal and regulatory agencies have expressed concerns about potential impacts from increased ground-water pumping on local and regional water quantity and quality, with particular concern for water rights issues and on the future availability of water to support natural spring flow and native vegetation. Before concerns for potential impacts from pumping can be addressed, municipal and regulatory agencies have recognized the need for additional information and improved understanding of geologic features and hydrologic processes that control the rate and direction of ground-water flow in eastern and central Nevada.

In response to concerns about water availability and limited geohydrologic information, Federal legislation was enacted in December 2004 (Section 301(e) of PL 108–424, Lincoln County Conservation, Recreation, and Development Act of 2004; short title, Lincoln County Land Act) that directed the Secretary of the Interior, through the U.S. Geological Survey (USGS), the Desert Research Institute (DRI), and a designee from the State of Utah, to conduct a water-resources study of the alluvial and carbonate aquifers in White Pine County, Nev., and adjacent areas in Nevada and Utah. The main objectives of the study, termed the Basin and Range Carbonate Aquifer System study, or the BARCAS study, were to evaluate: (1) the extent, thickness, and hydrologic properties of aquifers in the study area, (2) the volume and quality of water stored in these aquifers, (3) subsurface geologic structures controlling ground-water flow, (4) ground-water flow direction and gradients, and (5) the distribution and rates of recharge and ground-water discharge. Geologic, hydrologic, and supplemental geochemical information were integrated to determine individual basin and regional ground-water budgets. A draft report containing the preliminary results of the BARCAS study was released for public comment in Spring, 2007 (Welch and Bright, 2007); final results will be summarized in a USGS Scientific Investigations Report (SIR) that will be prepared in cooperation with DRI and the State of Utah, and submitted to Congress by December 2007. The BARCAS study final report will be supported by a series of USGS reports, including this report, and the DRI Hydrologic Sciences Reports that document, in greater detail than the BARCAS study final report, important components of this study.

The BARCAS study area encompasses about 35,000 km^2, including about 80 percent of White Pine County, and parts of Elko, Eureka, Nye, and Lincoln Counties in Nevada, as well as parts of Tooele, Millard, Beaver, Juab, and Iron Counties in Utah (fig. 1). The BARCAS study area lies within the Carbonate Rock Province, a relatively large area extending from western Utah to eastern California (fig. 1) where ground-water flow is predominantly or strongly influenced by carbonate-rock aquifers (Winograd and Thordarson, 1975; Bedinger and others, 1989; Dettinger and others, 1995; Harrill and Prudic, 1998). Much of the carbonate-rock aquifer is fractured, and these fractured rocks, where continuous, form a regional flow system that receives recharge from higher altitude areas in White Pine County where these fractured carbonate rocks are exposed. Water moving through the carbonate aquifer provides some recharge to overlying basin-fill aquifers, sustains many of the larger, perennial lower elevation springs in the study area, and hydraulically connects similar carbonate-rock aquifers in adjacent basins. Most areas in White Pine County, Nev., are within four regional ground-water flow systems (fig. 1) — the larger Colorado and Great Salt Lake Desert flow systems, and the smaller Goshute Valley and Newark Valley flow systems.

Production of ground water from the BARCAS study area could impact water accumulations in three general types of aquifer materials: consolidated Paleozoic carbonate bedrock, and basin-filling Cenozoic volcanic rocks and unconsolidated Quaternary sediments. At present, the full impact of extracting ground-water from any or all of these potential, valley-graben reservoirs is not fully understood. A thorough understanding of intermontane basin stratigraphy, mostly concealed by the youngest unconsolidated deposits that blanket the surface in these valleys, is critical to an understanding of the regional hydrology in this area.

The middle Tertiary geologic evolution of east-central Nevada is dominated by volcanic events that produced many ash-flow tuffs deposited during caldera-forming eruptions (Best, Christiansen, and others, 1989). Fractured Cenozoic volcanic rocks near the major volcanic fields are locally thick enough to be important subregional aquifers that interact with the regional flow through the underlying Paleozoic carbonate rocks (Dettinger, 1989; Harrill and others, 1988). Eruption dynamics cause ash-flow sheets to be distributed as much as hundreds of kilometers from their sources, to pond in topographic lows, and to mantle topography. Outflow thicknesses of individual ash-flow sheets that form a variety of tuffs can be hundreds of meters and the aggregate thickness of the outflow deposits that erupted from multiple calderas in east-central Nevada can be kilometers thick. Within the BARCAS study area, eruption of many of the ash-flow tuffs occurred relatively early in the extensional history of the area (Axen and others, 1993). As a consequence, regionally distributed ash-flow tuffs are preserved deep in the stratigraphy of the downfaulted basins, often covered by thick intervals of younger sedimentary deposits.

Because eruptive events that caused caldera formation are such major parts of the geologic framework in east-central Nevada, a general understanding of caldera dynamics and the distribution and thickness of outflow tuffs is critical to understanding the ground-water hydrology of this area. This report presents a literature-based compilation of geologic data, especially thicknesses and lithologic characteristics, for Tertiary rocks (mostly volcanic) that are presumably present in the subsurface of the intermontane valleys, which are prominent features of this area. In addition, the calderas themselves, as well as their associated structural features, are addressed because these features are significant relative to the area's ground-water hydrologic framework. These data are intended to support analysis for the extent, thickness, and hydrologic properties of volcanic-rock aquifers for the BARCAS study.

Geologic Setting

Processes related to large-volume ash-flow eruptions and associated caldera collapses are enumerated by Smith and Bailey (1968) and by Lipman (1984) and are summarized below. Calderas can be as much as 120 km in diameter, are structurally complex features, and most are bounded by a pair of geologic discontinuities, a structural margin and a topographic margin (fig. 2), both of which may be obscured by subsequent volcanism and erosion. These discontinuities are generally concentric and related to the structural collapse that is the hallmark of caldera-forming eruptions. Calderas form when large volumes of magma are nearly instantaneously erupted from shallowly emplaced magma reservoirs. As an eruption of this type ensues, the associated magma reservoir is partially evacuated by the eruption of frothy magma, and the central block of roof rock that lay above the reservoir collapses downward along a series of arcuate faults. The resulting system of faults forms a generally circular system of normal faults that constitute the caldera's structural margin. The lithologic discontinuity across the steeply inclined structural margin can be profound and can extend to depths of several kilometers. The resulting caldera wall begins to retreat outward as landslides calve off the oversteepened walls and contribute material to the deepening depression caused by the eruption and concomitant central collapse of the volcanic edifice (fig. 2). Outward retreat of the caldera boundary by subsequent landsliding forms a second, more gently inclined concentric discontinuity known as the topographic margin. Simultaneous with central collapse and landslide formation, the evolving central depression begins to be filled by the volcanic products derived from the ongoing eruption. This rapidly evolving intracaldera environment is usually filled by a kilometers-thick accumulation of ash-flow tuff and interleaved landslide materials (fig. 2). The discontinuity across the caldera's topographic margin, between intracaldera tuff and the country rock that host the caldera, can be at least as profound as that across the structural margin. Following caldera-forming eruptions, some of these igneous systems experience a central upward resurgence of unerupted magma from the underlying magma reservoir. Resurgence further complicates and disrupts the geology within the caldera (fig. 2).

The Cenozoic geologic evolution of east-central Nevada is dominated by a broad southward sweep of essentially calc-alkaline igneous activity (McKee, 1971; Cross and Pilger, 1978; McKee and Noble, 1986; Best, Christiansen, and others, 1989) with volcanic rocks, especially ash-flow tuffs, deposited during caldera-forming eruptions (Best, Christiansen, and others, 1989). Between about 30 and 25 Ma, caldera-related eruptions from two major centers, the Indian Peak caldera complex (IPCC, fig. 3) and the Central Nevada caldera complex (CNCC, fig. 3), formed a broad zone of voluminous upper Oligocene–lower Miocene volcanic rocks (Best, Christiansen, and others, 1989) that extended across Nevada and Utah. Subsequently, ash-flow eruptions from numerous nested calderas of the 23 to 13 Ma Caliente caldera complex resulted in regionally extensive ash-flow tuffs that are centered in the east-central part of Lincoln County (Scott and others, 1995) (fig. 3).

The Indian Peak caldera complex (IPCC, fig. 3), centered on the eastern side of Lake Valley in the northern part of Lincoln County, erupted on the order of 10,000 km^3 of volcanic rock between about 32 and 27 Ma (Best, Christiansen, and Blank, 1989). At least four major calderas have been identified within this complex (fig. 3) based on the presence of thick intracaldera tuff sequences and collapse breccias; two other calderas are inferred from the presence of regionally extensive ash-flow sheets (Best and Grant, 1987; Best, Christiansen, and Blank, 1989). Best, Christiansen, and Blank (1989) estimated that ash-flow tuffs erupted from the Indian Peak caldera complex alone cover about 55,000 km^2 in east-central Nevada. The spatial distribution of circular, caldera-related ring fracture systems and faults related to the Indian Peak caldera complex in east-central Nevada and west-central Utah were compiled by Loucks and others (1989) and Williams and others (1997).

The Central Nevada caldera complex (CNCC, fig. 3), in the northern part of Nye County, was even larger than the Indian Peak caldera complex. The Central Nevada caldera complex may include as many as 12 calderas and there are multiple sheets of rhyolite tuff with larger volumes than those in the Indian Peak caldera complex (Best, Christiansen, and others, 1989; Best and others, 1993). Eruptions from this complex were protracted, beginning at about 35.3 Ma and extending to 22.6 Ma (Best and others, 1993).

The Caliente caldera complex (CCC, fig. 3), about 80 km to the south of the Indian Peak caldera complex, erupted several thousand cubic kilometers of volcanic material between about 23 and 19 Ma (Williams, 1967). The dimensions of the Caliente caldera complex are about 80 km east-west and 35 km north-south, unusually elongated for a major caldera complex. The Caliente caldera complex consists of numerous nested calderas of 23–13 Ma, including the Clover Creek caldera, north and east of Caliente, which was the source of the densely welded Bauers Tuff Member of the Condor Canyon Formation, and the Delamar caldera, which makes up most of the western part of the complex and was the main source for the 18.3 Ma Hiko Tuff (Rowley and others, 2001).

A smaller volume, but locally important, ash-flow tuff called the Kalamazoo Tuff by Gans and others (1989) is widely distributed across northern White Pine County, Nev., and adjacent areas of Utah. This tuff, and associated overlying volcanic rocks, is inferred to have a source area in the northern part of Spring Valley (KT, fig. 3); eruptive volume may be 240–340 km^3 (Gans and others, 1989), an order of magnitude smaller than the largest ash-flow tuffs from the caldera complexes described above.

A final consideration concerning the middle Tertiary volcanic stratigraphy of east-central Nevada pertains to the lavas (and associated pyroclastic and volcaniclastic deposits) that are a significant, though not especially voluminous, part of the geologic framework of this area. Best, Christiansen, and others (1989) suggested that lavas constitute only about 10 percent of the total volume of Cenozoic volcanic rock in this region. However, because this is not an inconsequential amount of rock, lava flow thicknesses were considered as a possible contribution to Tertiary sections in the intermontane valleys of east-central Nevada. Most of these lavas are andesitic to rhyolitic and are often associated with calderas in the area, although there are locally important accumulations that are not associated with calderas, such as the volcanic rocks at the south end of Butte Valley, 30 km northwest of Ely, Nev. (Feeley and Grunder, 1991). Lava flow eruption dynamics typically result in discontinuous deposits that are not as broadly distributed around eruption sources, or as far traveled as ash-flow tuffs. The presence and thicknesses of individual lava flow sequences in the stratigraphic sections of the intermontane valleys is more difficult to determine than that for ash-flow tuffs, and can potentially lead to significantly greater uncertainty relative to intermontane valley Tertiary volcanic rock thickness estimates. In addition, lava flow rocks may have very different porosity, fracture styles, and fracture intensity than adjacent rocks in this area, and so may be spatially associated with significant ground-water hydrology discontinuities. Consequently, the thicknesses, lithologic character, and hydrologic properties of middle Tertiary lava flow rocks, as well as all other rock types that constitute parts of the hydrologic framework in east-central Nevada, must be well defined in order to accurately define the hydrologic framework for the region.

As a result of pyroclastic eruptions, caldera formation processes, and wide distribution of the associated ash-flow tuffs, calderas and their erupted products can profoundly influence, in a myriad of ways, ground-water hydrology in terranes that host these features. First, in trying to determine the types and thicknesses of geologic materials that may be preserved in the intermontane valleys of east-central Nevada, one must consider the likelihood that significant accumulations of middle Tertiary ash-flow tuff are preserved in many of these valleys. The lithologic characteristics of these rocks must be considered with regard to their ability to serve as water reservoirs, the extent of their hydraulic conductivity, and their interconnectedness to reservoirs either above in basin-fill sedimentary deposits or below in the Paleozoic rock aquifers. Next, the role of the topographic and structural margins with regard to ground-water hydrology must be considered. Depending on the geologic characteristics of these features, they may serve as either conduits or impermeable interfaces to ground-water flow. Similarly, the nature of the lithologic contrast between rocks exposed on either side of these discontinuities must be considered. The nature of the lithologic juxtaposition can have profound affects on ground-water storage and flow frameworks. In addition, the intersections between modern intermontane valleys and older intracaldera features must be considered. Places where intermontane valleys intersect intracaldera rocks and structures are places where profound geologic discontinuities may be present. In particular, structural and lithologic discontinuities present in these places can impact inferred reservoir geometry as well as ground-water flow. The distribution of calderas and associated eruptive products in east-central Nevada must be well understood in order to comprehend how they may contribute to the overall ground-water hydrology of this area.

Compilation Methods

Stratigraphic Thicknesses from Geologic Maps

Published geologic maps (fig. 4) and descriptions of map units were used to compile the aggregate thicknesses of Tertiary stratigraphic units present in each mountain range within the study areas (tables 1–13). These units are probably preserved in down-faulted, Cenozoic graben valleys of east-central Nevada and west-central Utah, and probably are about as thick in the valleys as they are in the flanking mountain ranges. Descriptions of map units contained on the published geologic maps almost always include thickness data, although usually somewhat generalized, for each unit whose distribution is shown on the geologic map. The Tertiary deposits are primarily volcanic rocks but include some interbedded sedimentary deposits. Mapped volcanic rocks are mostly regionally distributed ash-flow tuffs but also include significant volumes of lava flows. Geologic map units were subdivided into local and regional units (tables 1–13). Local units were those units with limited spatial extent within a single mapped quadrangle or mountain range; typically lava flows and Tertiary sedimentary rocks interbedded with tuff. Regional units were those units that occur in several quadrangles or mountain ranges. These volcanic-rock units are typically ash-flow tuffs associated with a caldera-forming eruption. Minimum and maximum thickness data were compiled for each map unit (tables 1–13), although many map unit descriptions indicate only maximum thicknesses. Unless minimum thicknesses were explicitly identified in source materials, minimum thicknesses are presumed to be zero. In order to estimate the stratigraphic thicknesses of Tertiary strata concealed beneath Quaternary deposits in each Cenozoic graben valley, we assume that their thicknesses are similar to those in the flanking mountain ranges.

The physiography of east-central Nevada is dominated by an alternating series of approximately north-trending valleys and mountain ranges. For the purposes of aggregating published thickness values, many of these valleys were divided into segments along their lengths, to allow consideration of geologic variability along valley lengths. The resulting data compilation (tables 1–13) preserves a level of detail commensurate with the detail and geologic variability portrayed on maps that depict the geology of ranges adjacent to each valley.

Stratigraphic thickness data were compiled as a series of valley segment components (tables 1–13). In most cases, each valley segment component of the tables presents two sets of thickness data. The first set presents thicknesses for Tertiary strata preserved in the range west of the valley segment, and the second for strata in the range east of the valley. In some cases, as noted on the tables, volcanic rocks and associated geologic data may be available for the range on one side of a valley but not on the other (for instance, the northern part of Lake Valley, table 5). In these cases, some proxy, as defined on the affected tables, is established for the missing information so as to enable valley thickness estimates.

Lava flows usually result in limited, near source distributions, whereas tuffs are distributed in a broad, regional fashion. Consequently, lava flows present in mountain ranges may not have flowed into regions that are now intermontane valleys. In contrast, ash-flow tuffs are known to have been deposited with much greater continuity over thousands of square kilometers. Recognizing these potential distribution variations, thickness data for Tertiary lava flow units were compiled separately from those for the ash-flow tuff units. An additional consideration relative to valley thickness estimates relates to whether ash-flow tuffs of east-central Nevada and west-central Utah were deposited as intracaldera tuff or as outflow tuff sheets. Intracaldera ash-flow tuff accumulations are known to be extremely thick (Lipman, 1984; Lipman and

Sawyer, 1985) and pertain to the intracaldera setting only. Consequently, only outflow ash-flow tuff thicknesses, those most likely to be representative of volcanic rocks that are presumably present in the subsurface of the intermontane valleys, were compiled. However, some valley segments, such as southern parts of Hamlin Valley (table 8) and Lake Valley (table 4), that are coincident with the intracaldera environment may preserve huge intracaldera ash-flow tuff thicknesses beneath Quaternary deposits.

Using the geologic relationships described above and interpolating stratigraphic thicknesses of Tertiary ash-flow tuffs between adjacent ranges, the thickness of tuffs potentially preserved in the intervening valleys may be estimated. The resulting tuff thickness estimates are not biased to the potentially erroneously high thickness estimates that would result from assuming that near-source lava flows are continuously preserved from adjacent ranges across intervening graben valleys. Interpolated thicknesses in valleys, based solely on regionally distributed ash-flow tuff thicknesses, are considered reasonable estimates of minimum concealed thicknesses of Tertiary rocks in the valleys. Accordingly, a highlighted entry in the center of each table presents the probable thickness range for Tertiary rocks in the associated valley segment. Because minimum thicknesses of the constituent stratigraphic units are very poorly known in most cases, the low end of these thickness ranges is unlikely to be diagnostic. The high end of each thickness range represents a value intermediate to the total thicknesses of regionally distributed Tertiary strata in the flanking mountain ranges.

In addition to thickness data, the data compilation (tables 1–13) contains additional geologic information. For each intermontane valley segment, stratigraphic units identified in one or both of the ranges that flank the valley are identified. One list identifies the stratigraphic units (mostly lava flows) that are deemed to be of local extent, and the other identifies those units (mostly major ash-flow tuffs) that are likely to be regionally distributed. Because the lithologic characteristics of each map unit potentially influence the hydrologic properties of these deposits, a brief description, including degree of welding, texture, and crystal content of stratigraphic units described in each pair of flanking ranges, is included (tables 1–13).

Published Isopach Data

A second method for estimating the stratigraphic thicknesses of Tertiary ash-flow tuffs that might be preserved in the intermontane valleys of east-central Nevada and western Utah is from published thickness (isopach) maps for individual ash-flow tuffs. The voluminous, regionally distributed Tertiary ash-flow tuffs have been extensively studied (see, for example, Best and Grant, 1987; Best, Christiansen, and others, 1989; du Bray, 1995; Scott and others, 1995) and the database derived from these studies is quite comprehensive. Consequently, synthesis of thickness data for many individual ash-flow tuffs is possible. Thickness data have been extremely important in identifying the sources of individual ash-flow tuffs and also in locating calderas that formed in response to major eruptive events. In general, the areas of greatest ash-flow tuff thickness are spatially coincident with calderas. However, mapped ash-flow tuffs in east-central Nevada and western Utah greatly outnumber identified calderas. In some cases, a caldera may be inferred from the volume of an ash-flow tuff unit, yet its location may be unknown because it has been subsequently disrupted by younger structural or erosional events, or buried by younger rocks.

Isopach maps have been compiled for most of the major, regionally distributed ash-flow tuffs of east-central Nevada and west-central Utah. One of the earliest efforts to compile isopach maps for this region was that of Williams (1967), who synthesized thickness data for ash-flow tuffs related to the Caliente caldera complex, including the Harmony Hills Tuff, the Condor Canyon Formation which comprises the Bauers Tuff and Swett Tuff Members, and the Leach Canyon Formation. Williams also compiled a maximum extent of distribution map for the Pahranagat Formation from the central Nevada caldera complex. Subsequent mapping of these rocks has resulted in refinements to the stratigraphic nomenclature (Rowley and others, 1995; Scott and others, 1995), but the initial thickness compilations remain valid. Isopach maps for some large-volume ash-flow tuffs from the central Nevada caldera complex, including the Windous Butte Formation, the Monotony Tuff, and the Shingle Pass Tuff were produced by Best, Christiansen, and others (1989). Best, Christiansen, and Blank (1989) also compiled thickness data for ash-flow tuffs of the Indian Peak caldera complex; this compilation includes isopach diagrams for the Cottonwood Wash Tuff, Wah Wah Springs Formation, Lund Formation, and Isom Formation. The distribution and thickness of the Kalamazoo Tuff and associated overlying volcanic rocks across northern White Pine County, Nev., and adjacent areas of Utah was portrayed by Gans and others (1989). Thickness maps are thus available for the majority of the voluminous, regionally distributed ash-flow tuffs present in east-central Nevada and west-central Utah.

The published isopach maps were scanned and georeferenced in a Geographic Information System (GIS) and the location and thickness values as measured at outcrops of individual tuffs were digitized from these published maps. In order to preserve the original author's interpreted contour patterns, additional thickness data were created by digitizing a regular series of points along each contour line of the isopach maps. For each tuff, these thickness data were gridded as 2,500-m square cells within the GIS to produce a digital thickness grid as raster data sets. Thickness was gridded using either inverse distance or simple kriging algorithms; the gridding methodology was chosen on the basis of how closely the digital grid resembled the original published contour map. Grids were locally hand-edited in order to recreate abrupt thickness changes at known or inferred caldera boundaries. Using this approach, digital thickness grids were created for the following ash-flow tuffs: the Kalamazoo Tuff (fig. 5), the Windous Butte Formation (fig. 6), the Monotony Tuff (fig. 7), the Shingle Pass Tuff (fig. 8), the Cottonwood

Wash Tuff (fig. 9), the Wah Wah Springs Formation (fig. 10), the Lund Formation (fig. 11), the Isom Formation (fig. 12), the Leach Canyon Formation (fig. 13), the Condor Canyon Formation (fig. 14), and the Harmony Hills Tuff (fig. 15). In each of these figures two maps are shown. The larger map portrays the thickness of the individual ash-flow tuff contoured using intervals that display most clearly the thickness variations of the unit. The smaller map in each figure shows the same thickness data, but contoured at intervals consistent with those used for the thickest tuffs in the region. Thus the reader may see the details of the thickness variations within each tuff and also gain an understanding of the thickness of the ash-flow tuff as compared to the largest eruptions in the study area. In many cases, the thickest intervals do not exactly correspond to mapped caldera boundaries. This disparity is usually the result of limited outcrop data; in most cases the thickness and distribution of the intracaldera fill on published isopach maps may be represented by a single data point. In a few cases, the caldera boundaries themselves are only generally located, or the thickness of the intracaldera volcanic rocks is poorly known due to disruption by younger structural events, or burial by younger rocks. Thickness data portrayed on the individual isopach maps were added together to produce a composite isopach map that combines the gridded thickness for all of the previously named units (fig. 16). The composite isopach map is dominated by the thick intracaldera accumulations within the Indian Peak caldera complex and the central Nevada caldera complex (fig. 3). The thickness of intracaldera rocks within the Caliente caldera complex (fig. 3) may be underrepresented in this compilation due to the relative lack of published thicknesses of intracaldera rocks; however, these eruptions were generally much smaller in volume than the other two main caldera centers. Using the composite isopach map (fig. 16), one can predict the relative thickness of outflow tuffs between the caldera complexes.

Comparison of Thickness Compilation Methods

The two thickness compilation methods may be compared at specific valley-axis locations by overlaying the gridded total thickness map and the predicted valley-axis thickness compiled from data contained in published descriptions of map units (fig. 17). A comparison of the two methods at these locations (fig. 18) suggests that the two methods yield generally similar results. Thickness predicted by the gridded data is necessarily generalized because it relies on interpolation between relatively scarce measured sections. Gridded thickness maps were created only for those tuffs for which published isopach maps were available. Certain regionally distributed tuffs, such as those emanating from the Marysvale volcanic field in south-central Utah (Rowley and others, 1979; Rowley and others, 1998) were not considered in this analysis and volcanic-rock thickness may be underestimated, especially in the valleys of western Utah. The thickness derived from descriptions of map units is principally affected by the fact that thicknesses presented in geologic descriptions of map units are somewhat generalized and imprecise in most cases. Stratigraphic thicknesses are typically reported as ranging from zero to a maximum value (tables 1–13), neither of which may be representative of the thickness commonly observed in outcrop.

Available subsurface data from oil and gas exploration wells drilled in valleys of east-central Nevada (Hess and others, 2004) and west-central Utah (Hintze and Davis, 2003) are shown on figures 17 and 18. These data are generally similar to the predicted values but also emphasize the degree of local variability and the limitations of such general compilations. For example, in Lake Valley one well intersected 826 m of volcanic rocks (fig. 17) whereas a second well about 15 km to the south did not encounter any volcanic rocks (fig. 17), even though this well is located within a buried caldera that is inferred to underlie Lake Valley. Farther to the east in northern Hamlin Valley and southern Snake Valley, one well penetrated over 320 m of volcanic rocks and did not penetrate the base of the volcanic sequence (fig. 17); another well only 4 km to the northeast encountered about 140 m of volcanic rocks before penetrating Paleozoic carbonate rocks below. In both of these situations, the bedrock exposures on either side of the valleys contain faulted Paleozoic rock outcrops blanketed by the Cenozoic volcanic section; projection of this outcrop geology into the subsurface would produce a variety of predicted thicknesses of volcanic rocks, depending on the degree of volcanic rock preservation and paleogeographic complexity of the surface on which they were deposited. These examples emphasize that methods of thickness compilation presented here may be of use in defining regional variations in predicted thickness, but are not appropriate for site-specific subsurface geology.

Summary

The middle Tertiary geologic history of east-central Nevada is dominated by volcanic events, especially emplacement of regionally distributed ash-flow tuffs deposited during caldera-forming eruptions. Regional ground-water studies such as the BARCAS study require a three-dimensional depiction of the extent and thickness of subsurface geologic units that provides a conceptual and numerical framework of the subsurface distribution of the aquifer materials. Typically, this requires the ability to predict the thickness of a rock unit that is of interest across a very large area on the basis of a small number of data points. Compilation of geologic data from published maps and reports provides a general understanding of the distribution and thickness of tuffs that are presumably present in the subsurface of the intermontane valleys and are critical to understanding the ground-water hydrology of this area. The data compiled in this report have been used as direct input in the construction of a simplified three-dimensional geologic model of the BARCAS study area (Watt and Ponce, 2007) and have also been used in water budget calculations for the BARCAS study area (Welch and Bright, 2007). Predicted thicknesses that are based on geologic descriptions of map units may overestimate or underestimate regional thickness trends because such descriptions often report a minimum and maximum thickness. It is possible that average thicknesses would provide a more likely estimate of tuff thickness at any particular location within the area addressed by this publication. Predicted thicknesses derived by combining isopach maps for individual tuffs are dependent on the availability of such maps and the underlying field data used to create the maps. Neither method is accurate for predicting local site-scale variability in volcanic-rock thickness, which can only be derived from a combination of drilling and geophysical methods.

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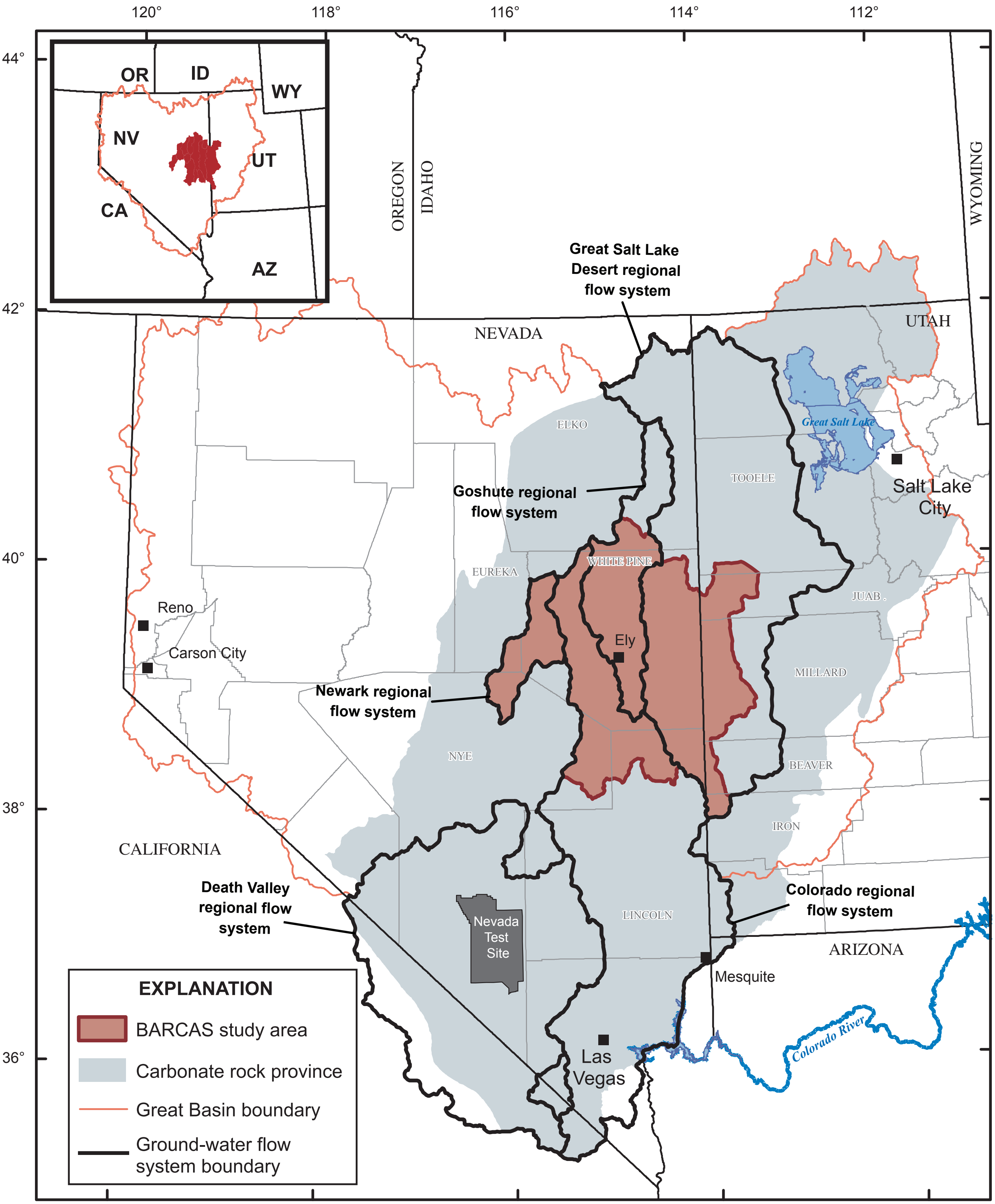


Base from USGS 1:100,000-scale digital data, 1979-1984.
1:1,000,000 scale watershed boundaries from USGS digital data.
Universal Transverse Mercator Projection, Zone 11, NAD83.

Figure 1. Carbonate rock province, BARCAS study area, and associated regional ground-water flow systems.

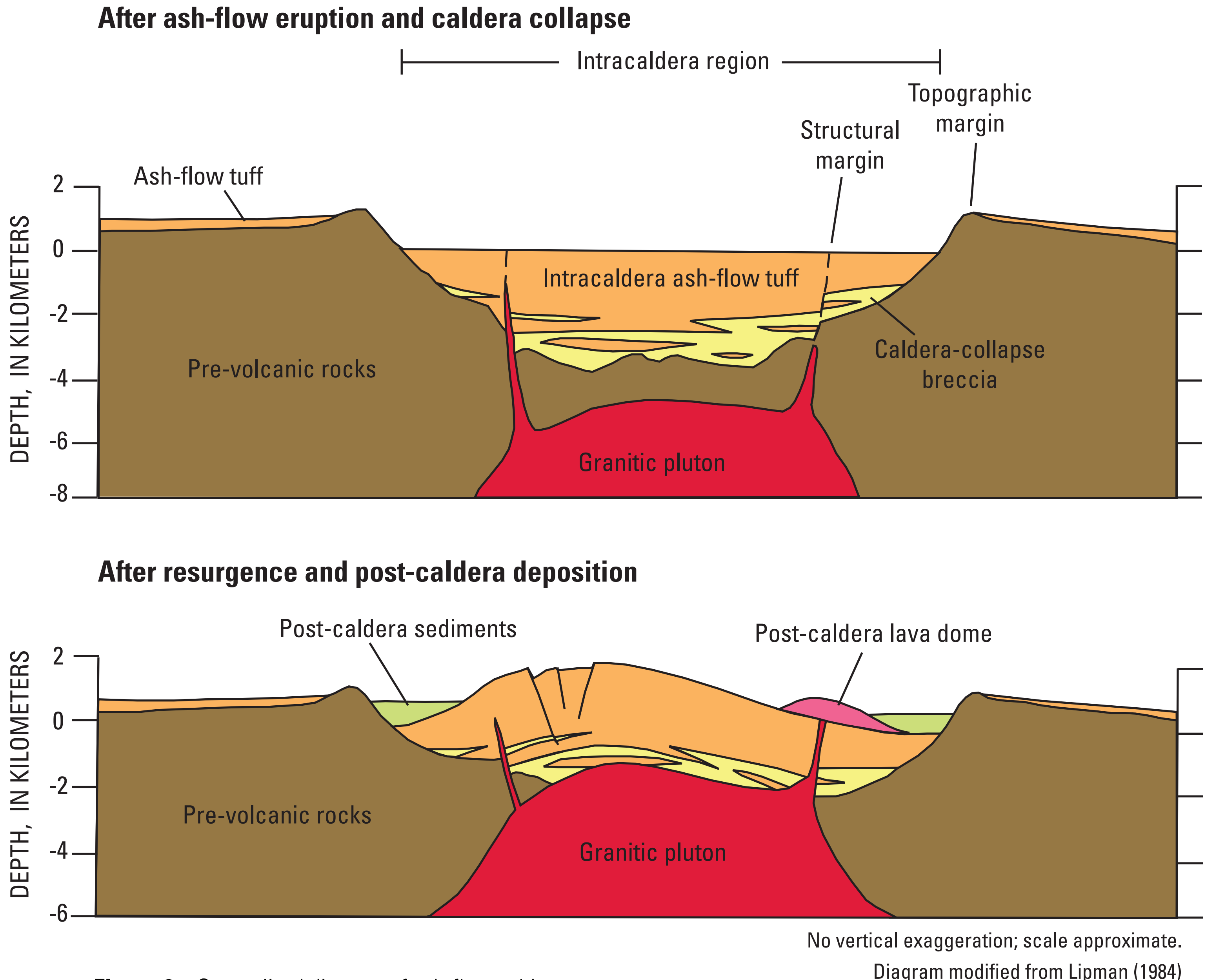


Figure 2. Generalized diagram of ash-flow caldera.

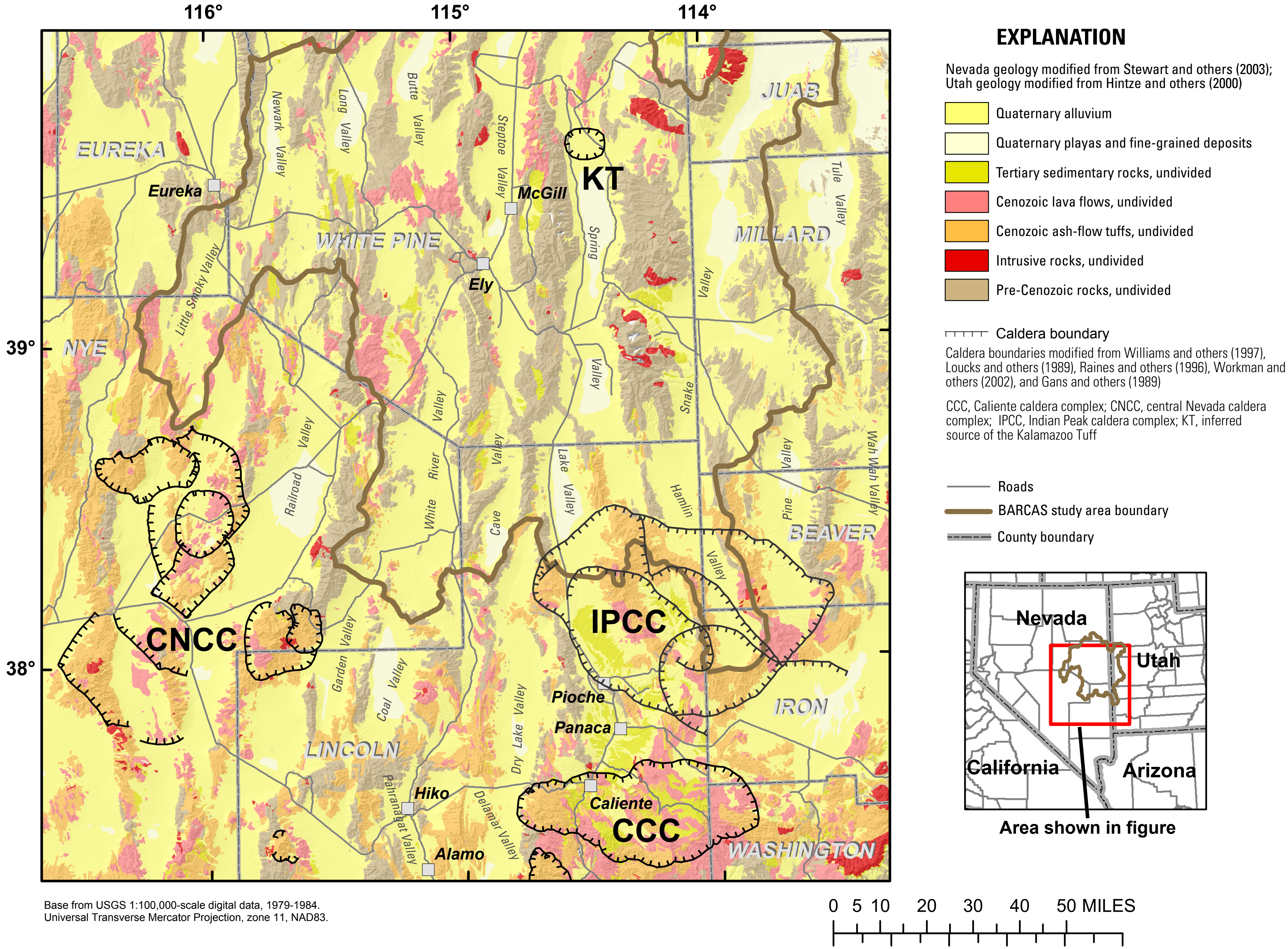


Figure 3. Generalized geology map and locations of calderas, eastern Nevada and western Utah.

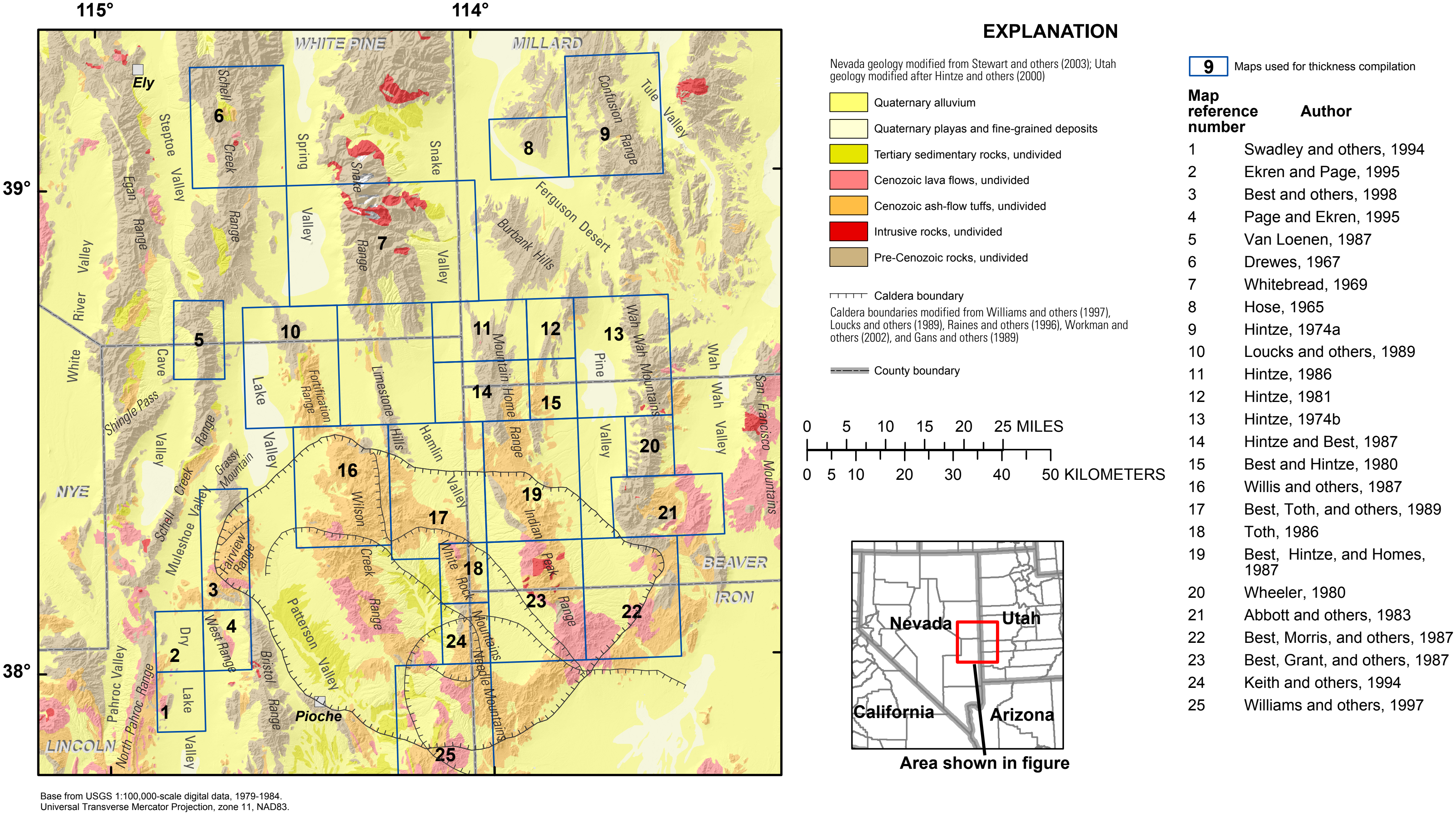


Figure 4. Index of geologic maps in the vicinity of the Indian Peak caldera complex used to compile volcanic rock thicknesses.

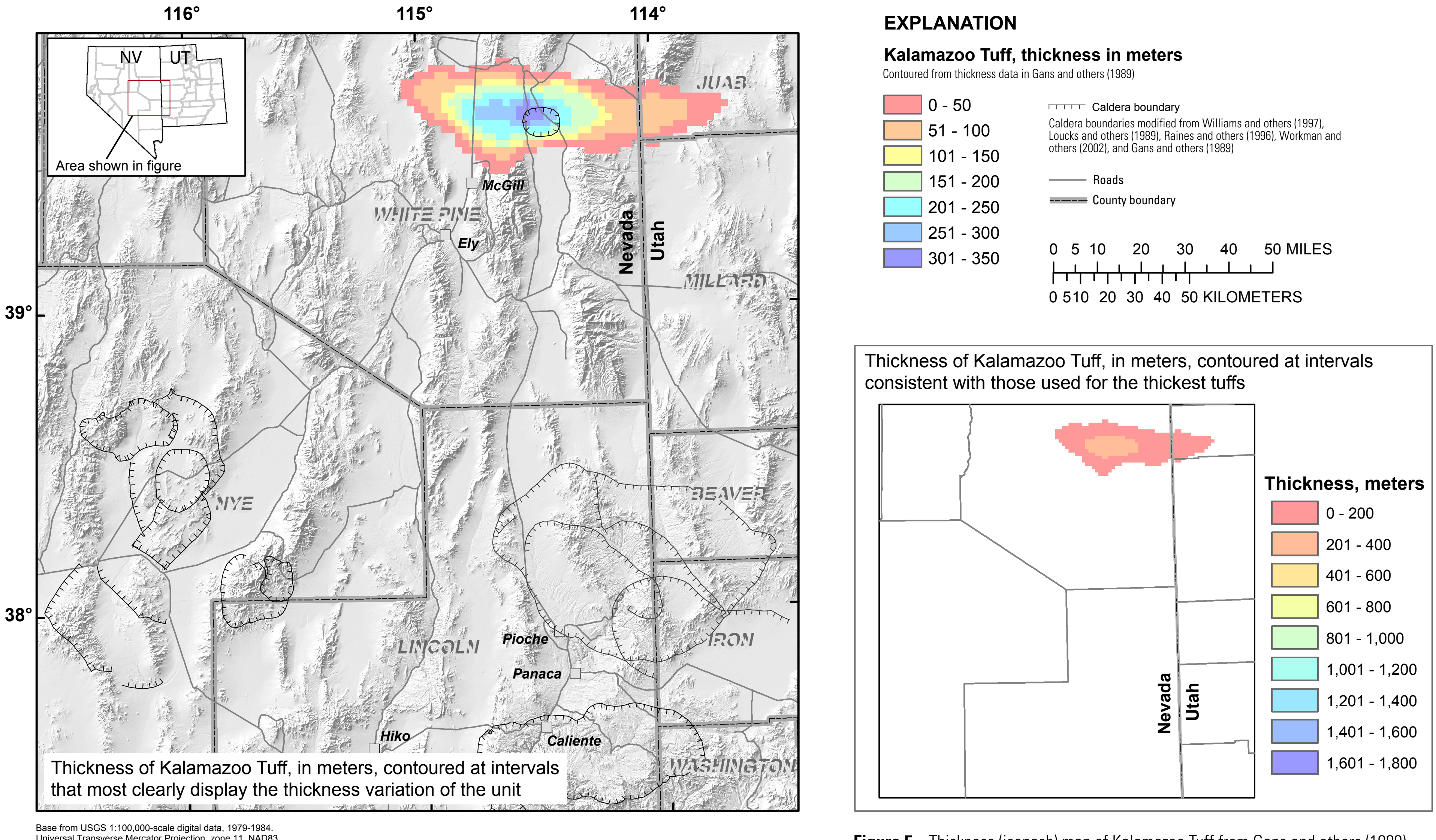
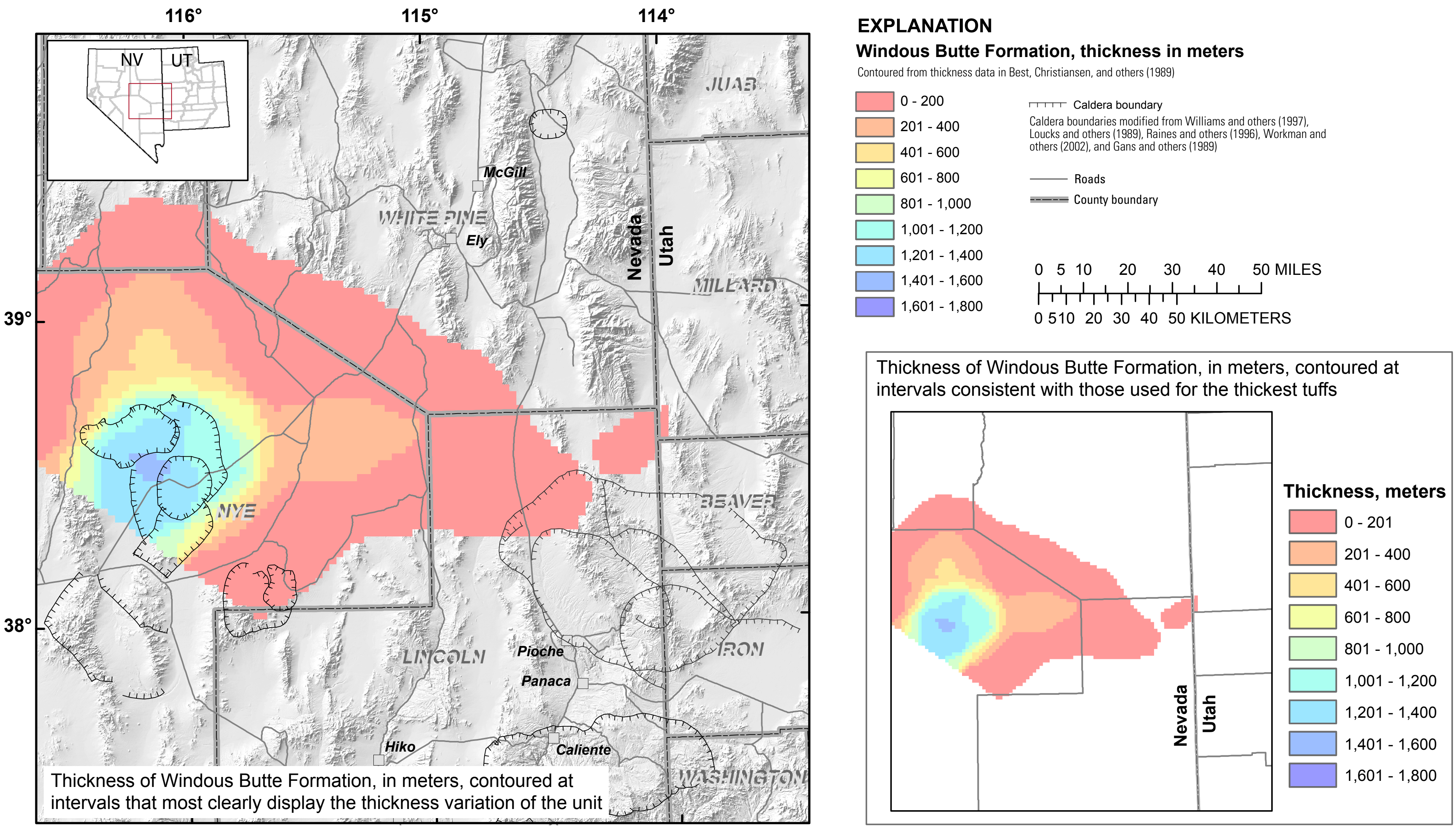


Figure 5. Thickness (isopach) map of Kalamazoo Tuff from Gans and others (1989).



Base from USGS 1:100,000-scale digital data, 1979-1984.
Universal Transverse Mercator Projection, zone 11, NAD83.

Figure 6. Thickness (isopach) map of Windous Butte Formation.

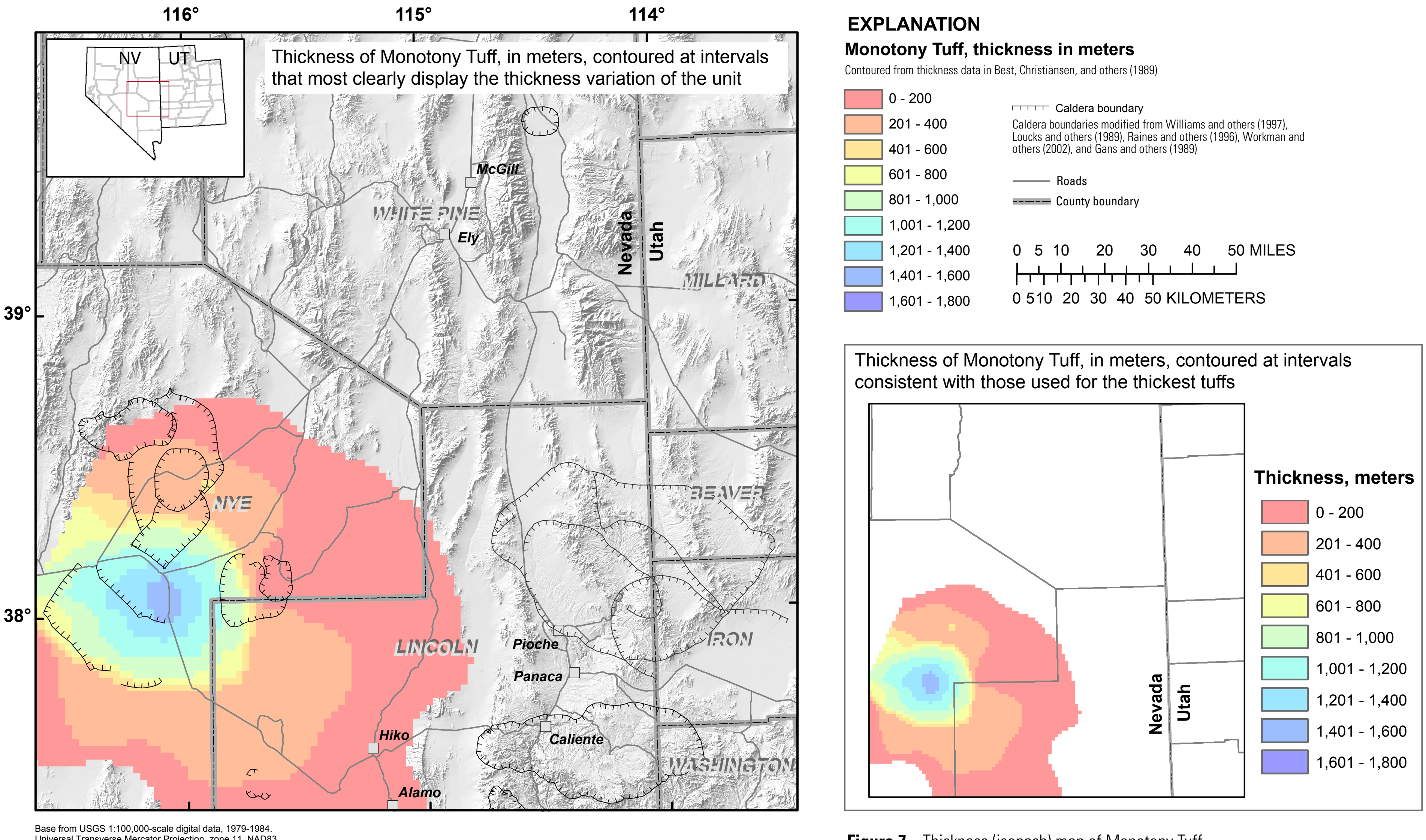
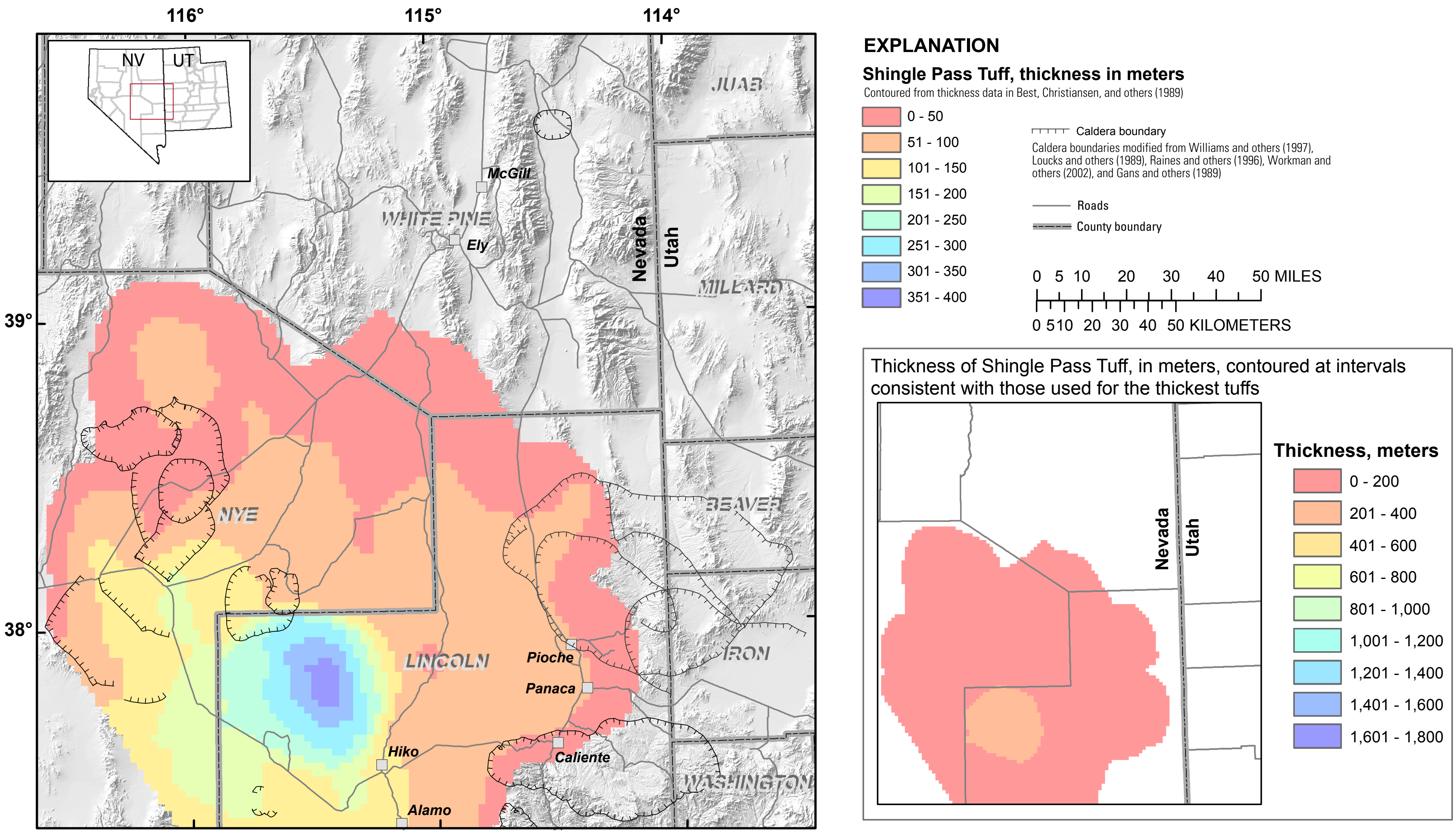
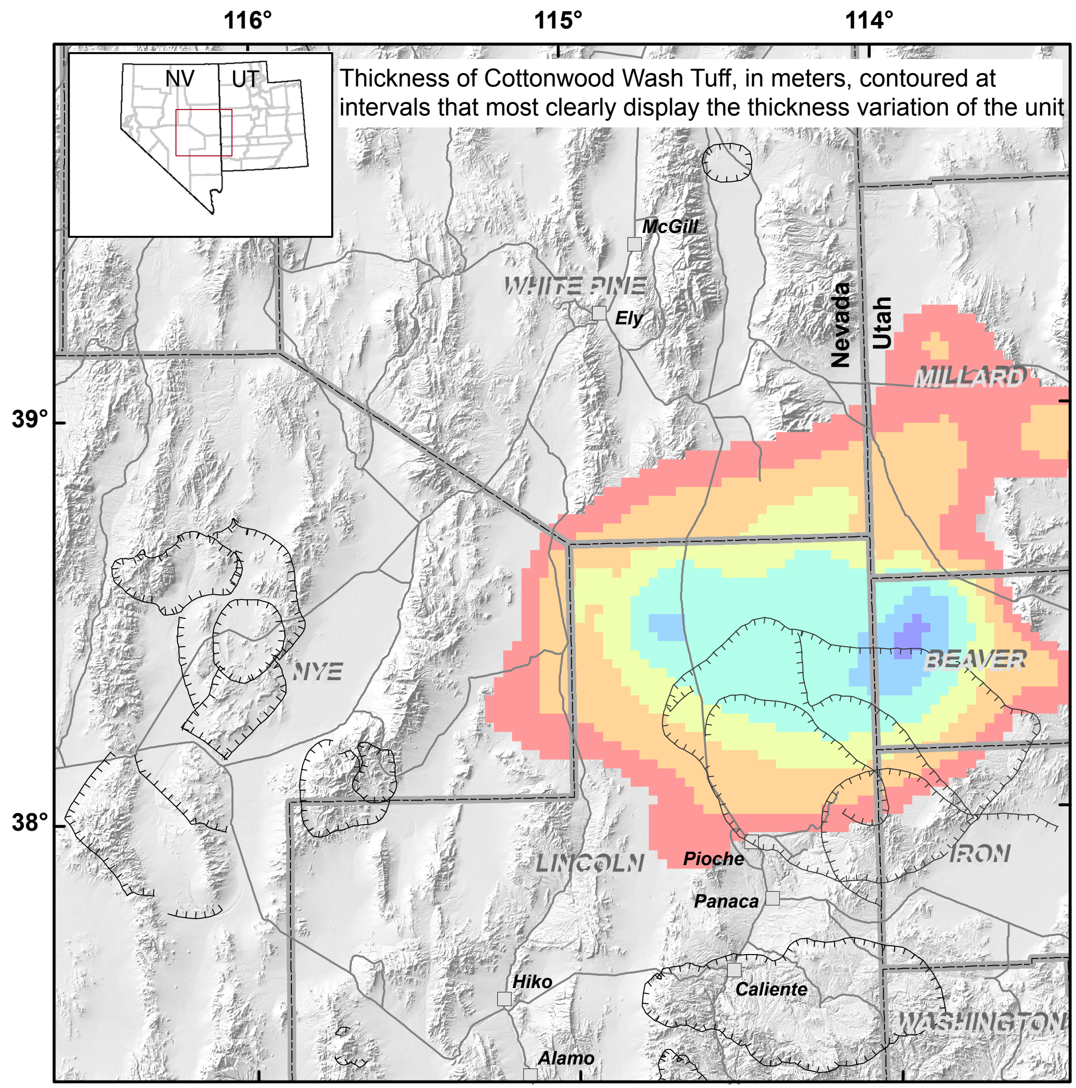


Figure 7. Thickness (isopach) map of Monotony Tuff.



Base from USGS 1:100,000-scale digital data, 1979-1984.
Universal Transverse Mercator Projection, zone 11, NAD83.

Figure 8. Thickness (isopach) map of Shingle Pass Tuff.



Base from USGS 1:100,000-scale digital data, 1979-1984.
Universal Transverse Mercator Projection, zone 11, NAD83.

EXPLANATION

Cottonwood Wash Tuff, thickness in meters

Contoured from thickness data in Best, Christiansen, and Blank (1989)

- 0 - 50
- 51 - 100
- 101 - 150
- 151 - 200
- 201 - 250
- 251 - 300

Caldera boundary

Caldera boundaries modified from Williams and others (1997), Loucks and others (1989), Raines and others (1996), Workman and others (2002), and Gans and others (1989)

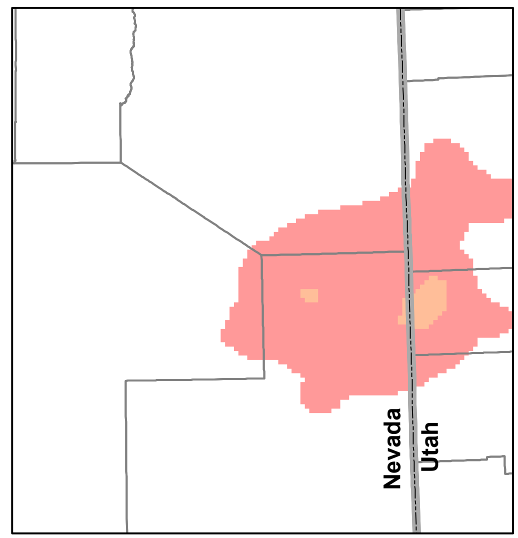
Roads

County boundary

0 5 10 20 30 40 50 MILES

0 5 10 20 30 40 50 KILOMETERS

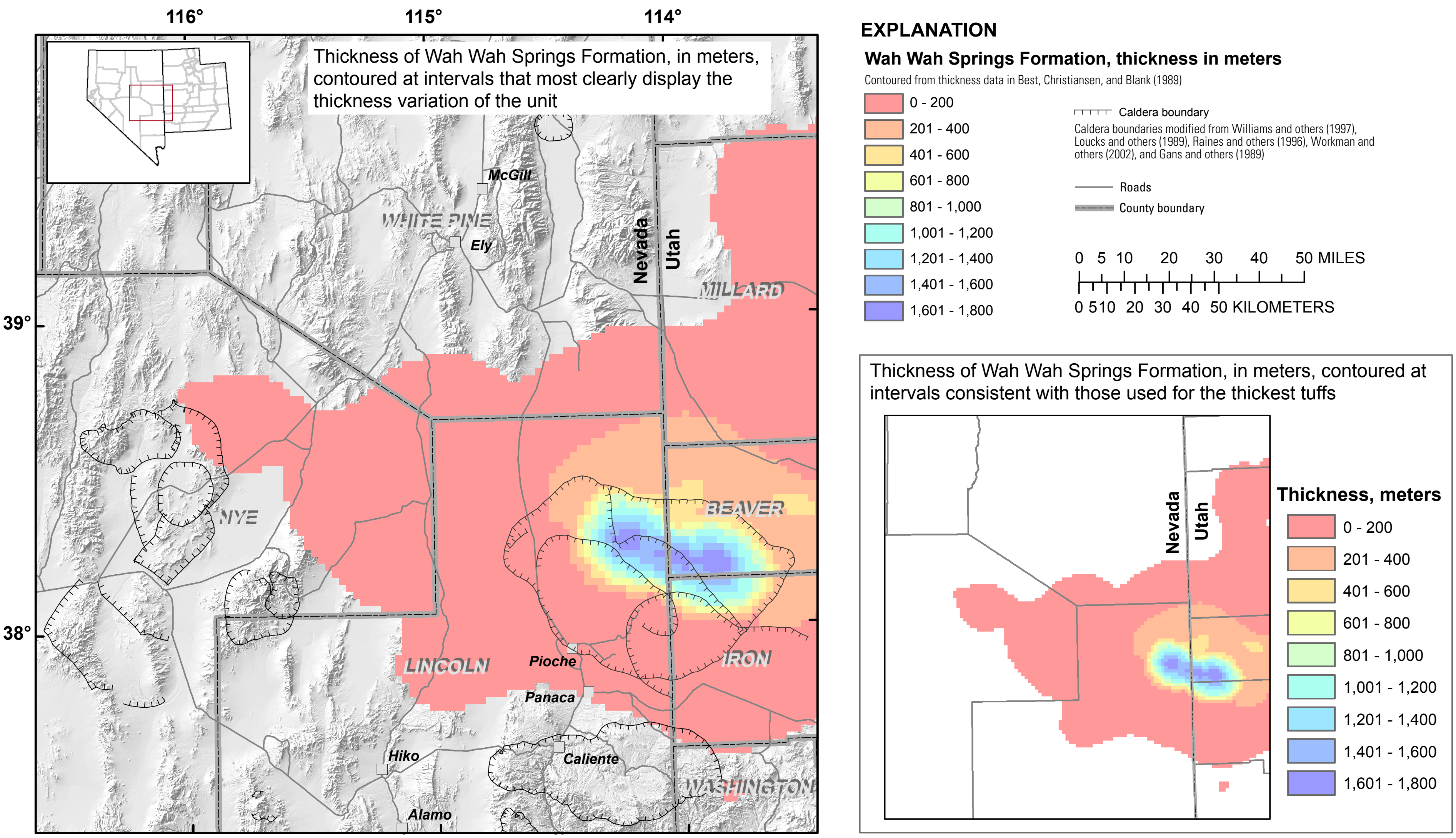
Thickness of Cottonwood Wash Tuff, in meters, contoured at intervals consistent with those used for the thickest tuffs



Thickness, meters

- 0 - 200
- 201 - 400
- 401 - 600
- 601 - 800
- 801 - 1,000
- 1,001 - 1,200
- 1,201 - 1,400
- 1,401 - 1,600
- 1,601 - 1,800

Figure 9. Thickness (isopach) map of Cottonwood Wash Tuff.



Base from USGS 1:100,000-scale digital data, 1979-1984.
Universal Transverse Mercator Projection, zone 11, NAD83.

Figure 10. Thickness (isopach) map of Wah Wah Springs Formation.

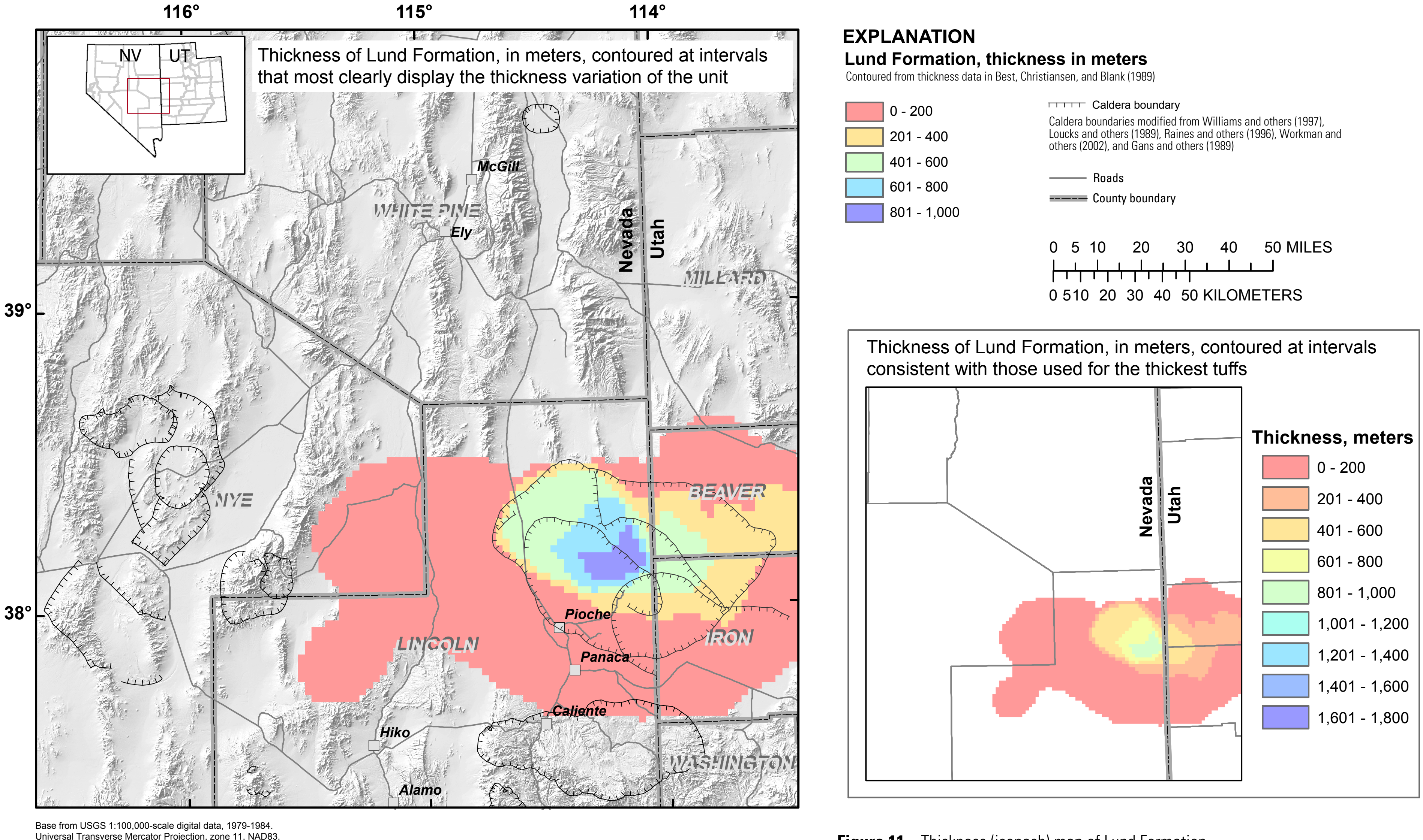
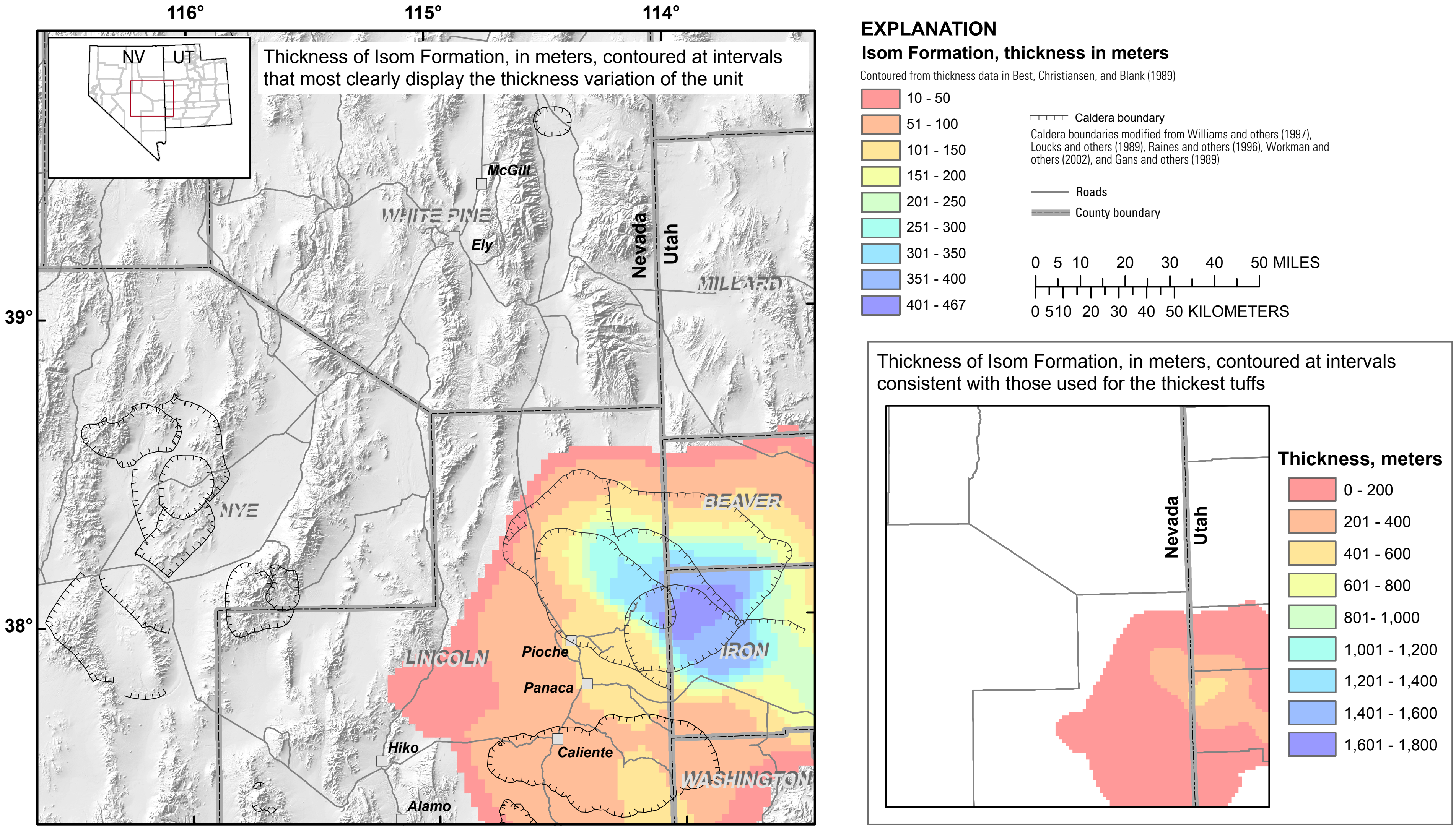


Figure 11. Thickness (isopach) map of Lund Formation.



Base from USGS 1:100,000-scale digital data, 1979-1984.
Universal Transverse Mercator Projection, zone 11, NAD83.

Figure 12. Thickness (isopach) map of Isom Formation.

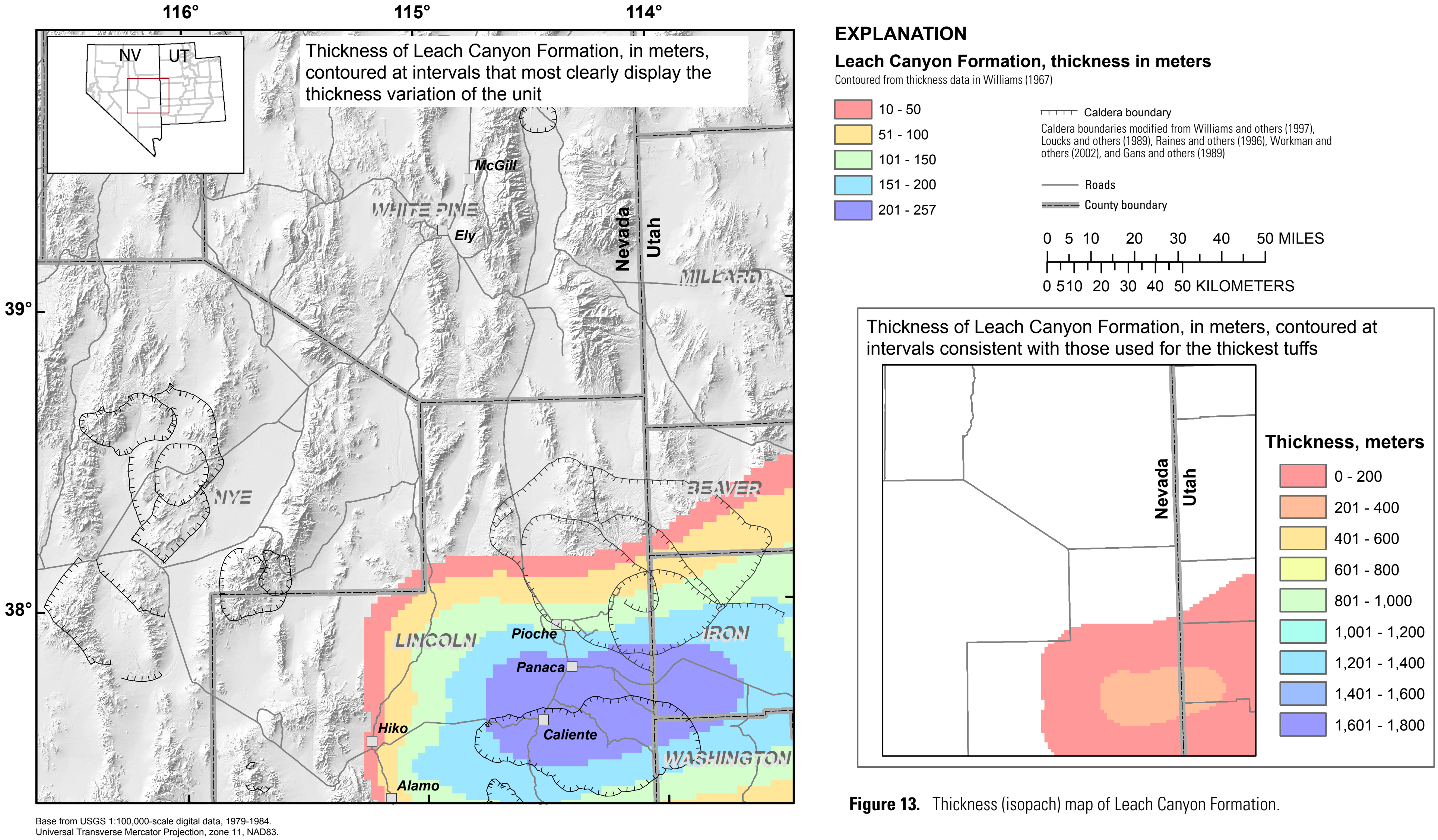
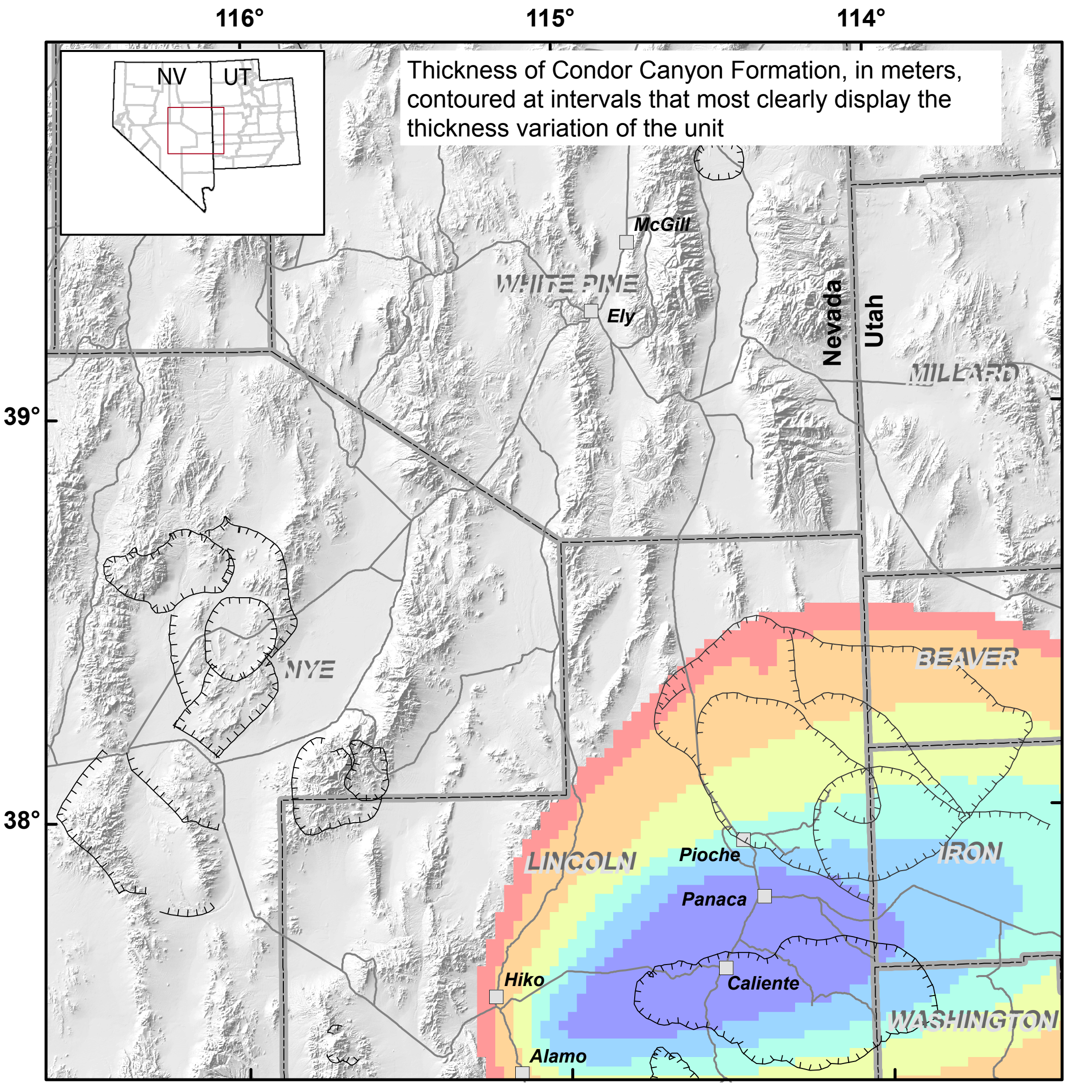


Figure 13. Thickness (isopach) map of Leach Canyon Formation.



Base from USGS 1:100,000-scale digital data, 1979-1984.
Universal Transverse Mercator Projection, zone 11, NAD83.

EXPLANATION

Condor Canyon Formation, thickness in meters

Contoured from thickness data in Williams (1967)

- 10 - 25
- 26 - 50
- 51 - 75
- 76 - 100
- 101 - 125
- 126 - 152

Caldera boundary

Caldera boundaries modified from Williams and others (1997), Loucks and others (1989), Raines and others (1996), Workman and others (2002), and Gans and others (1989)

Roads

County boundary

0 5 10 20 30 40 50 MILES

0 5 10 20 30 40 50 KILOMETERS

Thickness of Condor Canyon Formation, in meters, contoured at intervals consistent with those used for the thickest tuffs

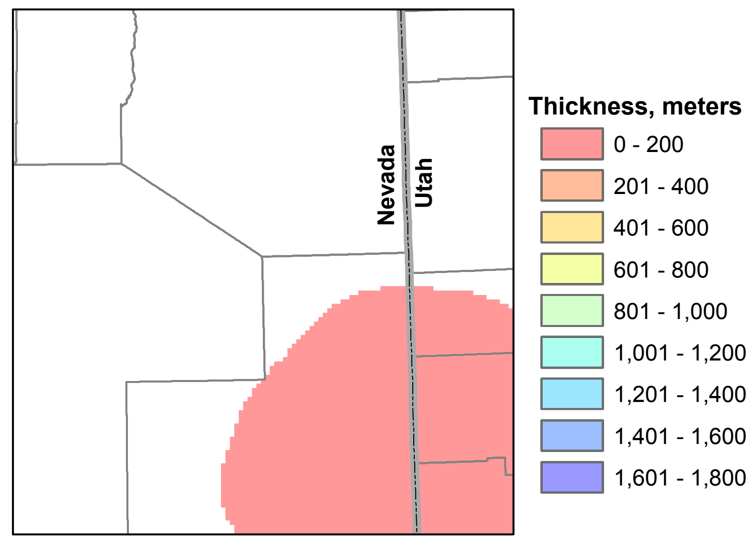
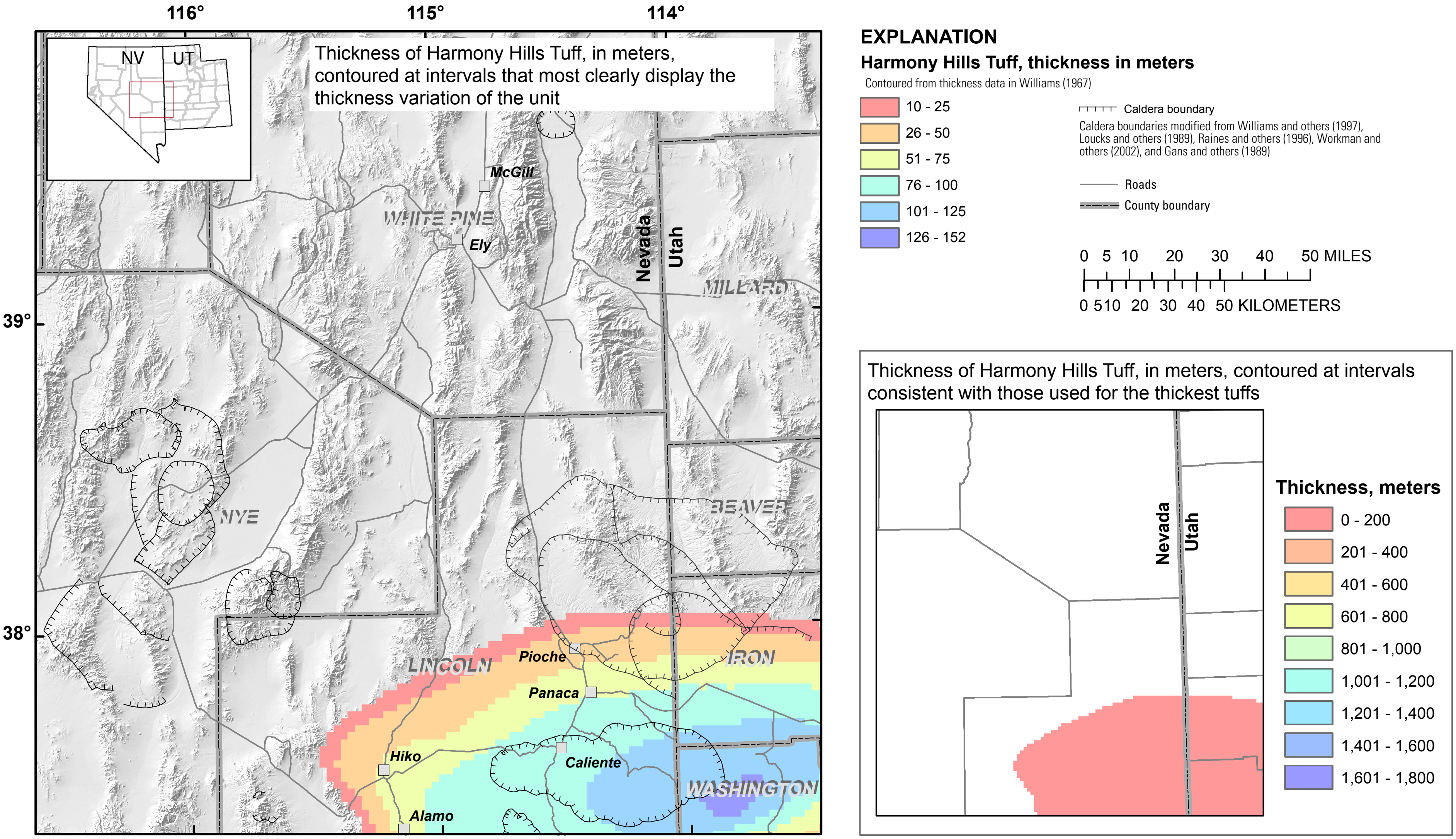
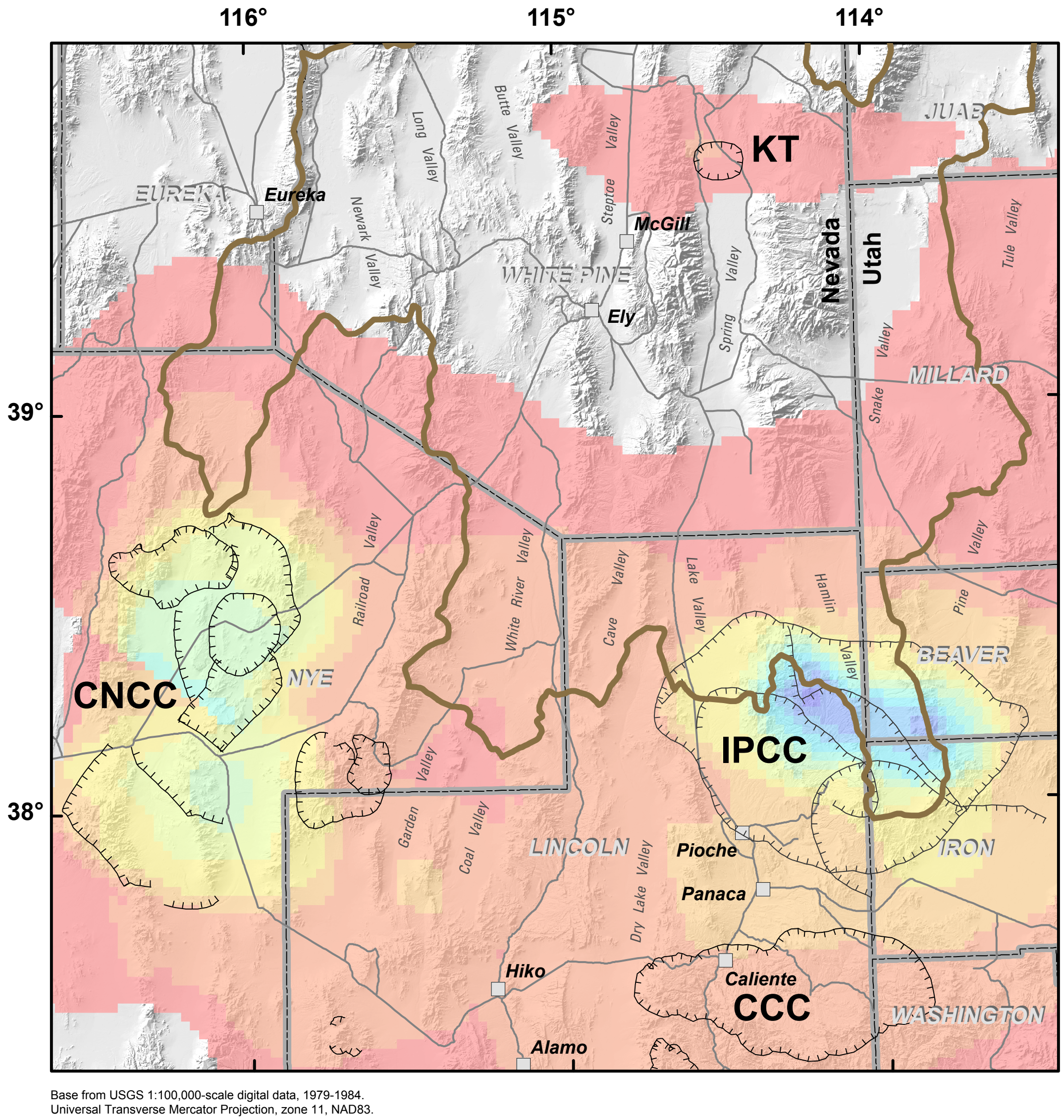


Figure 14. Thickness (isopach) map of Condor Canyon Formation.



Base from USGS 1:100,000-scale digital data, 1979-1984.
Universal Transverse Mercator Projection, zone 11, NAD83.

Figure 15. Thickness (isopach) map of Harmony Hills Tuff.



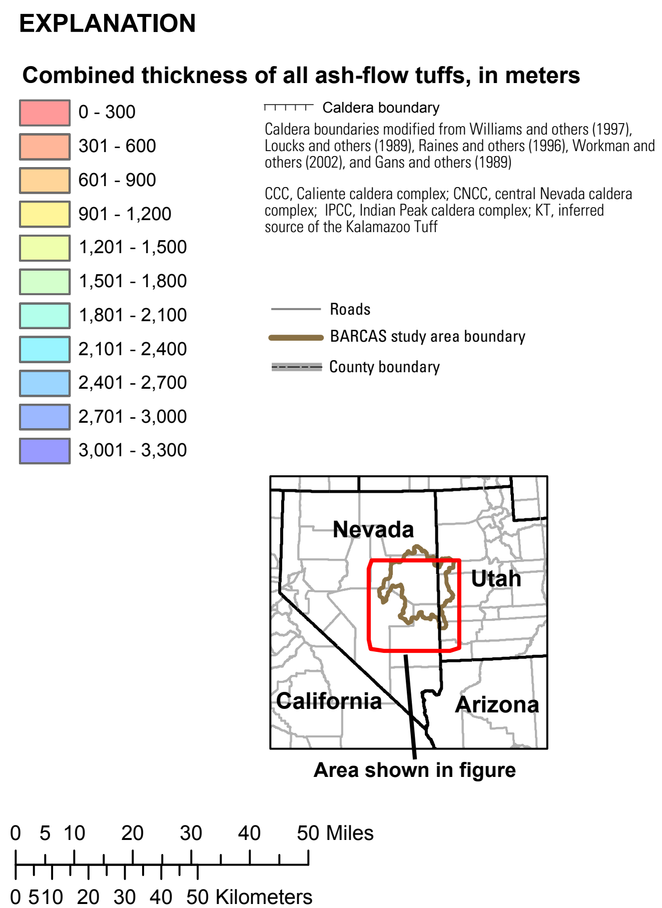


Figure 16. Aggregate thickness (isopach) map of all tuffs for caldera-related Tertiary volcanic rocks in east-central Nevada and west-central Utah.

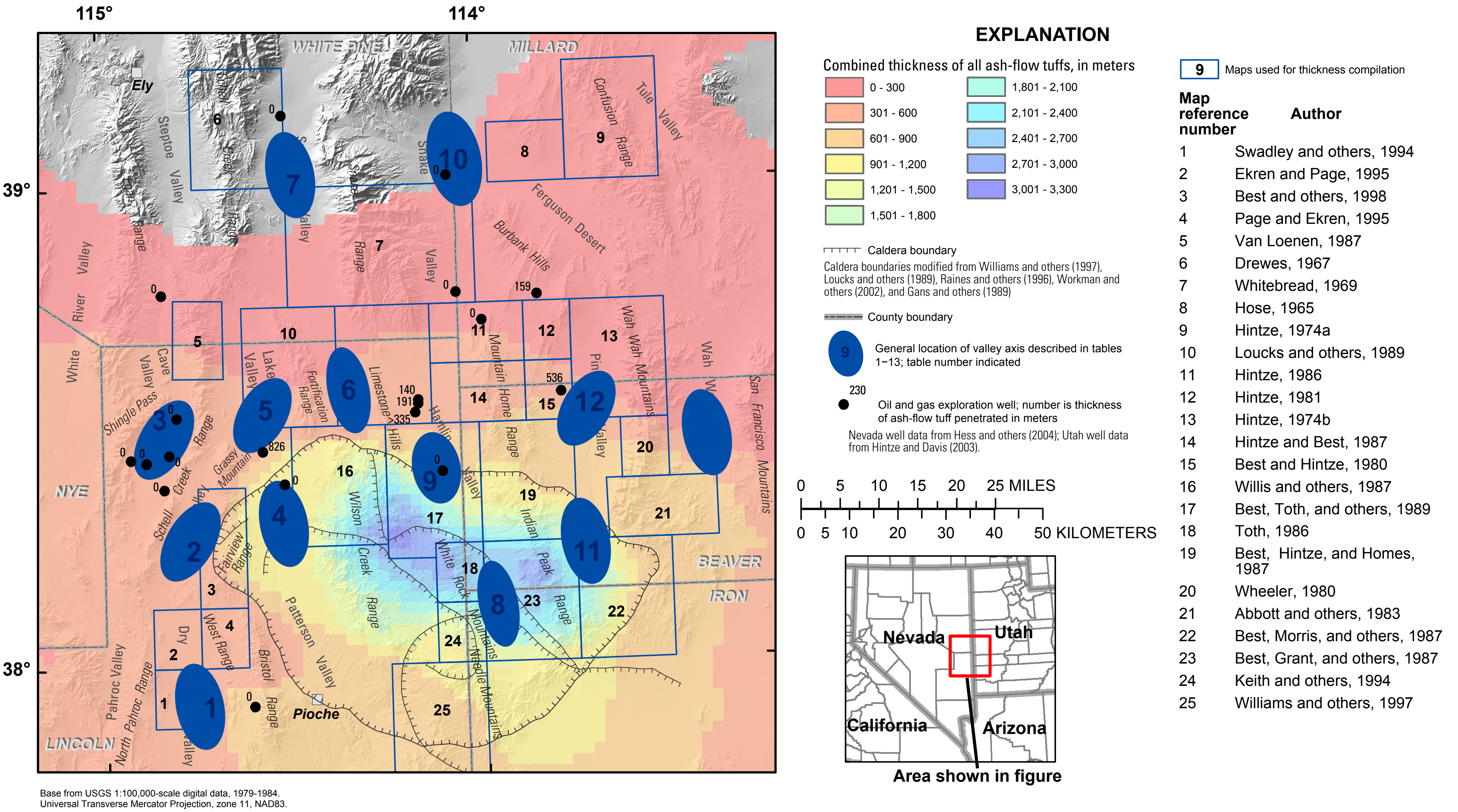


Figure 17. Volcanic thickness (isopach) map showing location of valley axes in eastern Nevada and western Utah described in tables 1–13.

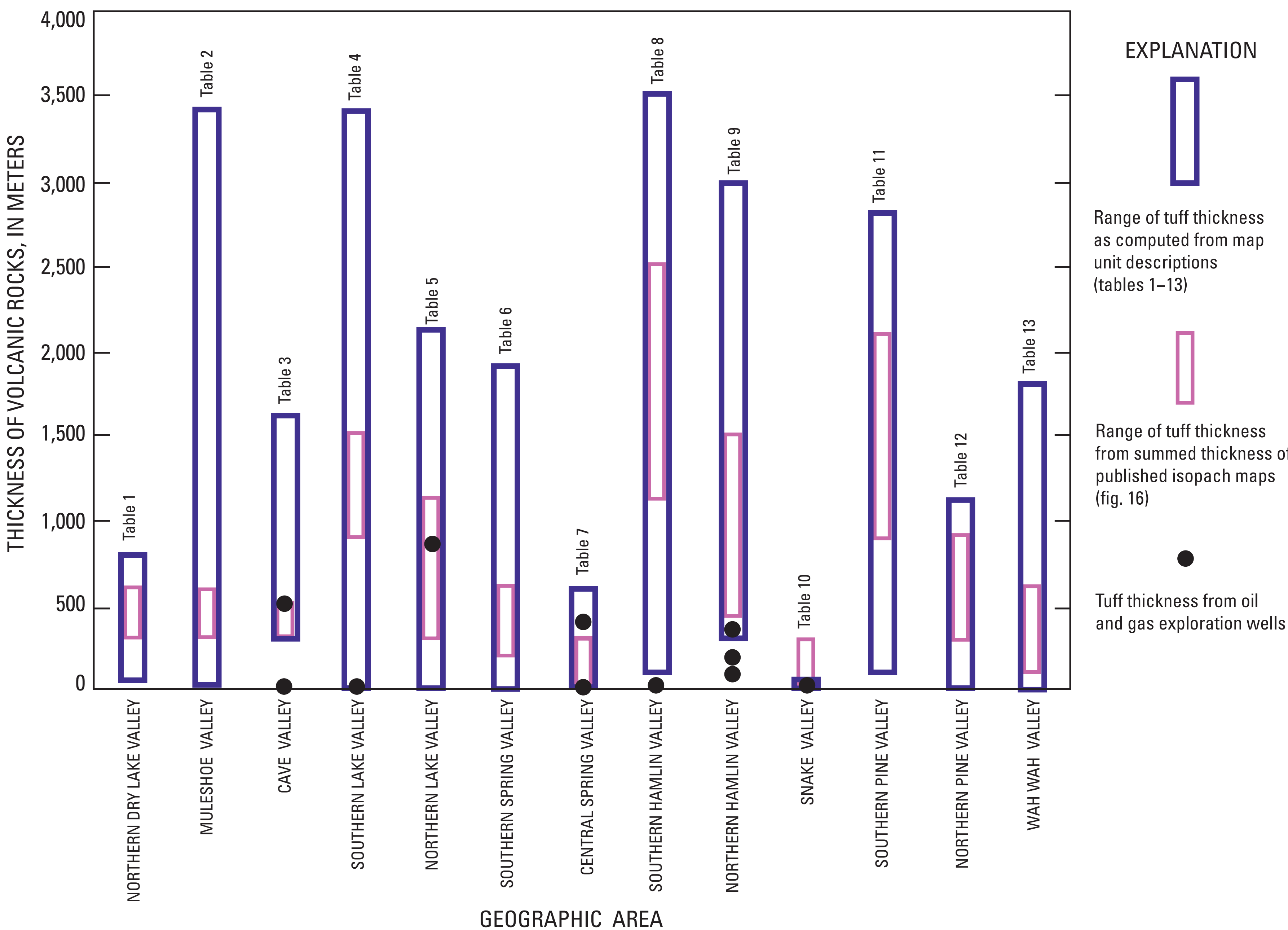


Figure 18. Comparison of tuff thickness compilation methods, east-central Nevada and west-central Utah. Associated table is listed at top of bar.

Table 1. Compilation of volcanic-rock thickness from mountain ranges flanking the northern part of Dry Lake Valley

[Thickness data for North Pahroc Range from Swadley and others (1994) and Ekren and Page (1995); thickness data for the West Range from Page and Ekren (1995); leaders (--), unit not present]

Description of geologic map units

Mountain range to the west: North Pahroc Range

Local Unit[1]	Regional Unit[2]	Minimum thickness, m	Maximum thickness, m	Lithology
Tts	--	0	200	Lacustrine sandstone and shale; also pebble conglomerate
Tb	--	0	13	Massive to vesicular basaltic lava flows
--	PF	0	20	Weakly to moderately welded rhyolite tuff; 15–35% crystals
--	CB	20	40	Densely welded rhyolite tuff; 20% crystals
--	BT	25	75	Weakly welded rhyolite tuff; 15% crystals
--	SP	20	30	Densely welded rhyolite tuff; 5–12% crystals
--	IS	0	5	Densely welded trachydacite tuff; 5–15% crystals
Tah	--	0	100	Massive, locally vesicular andesite lava flows; 35% crystals
	PC	0	6	Weakly to densely welded trachyte tuff; crystal poor
Tms	--	0	600	Massive to vesicular andesite lava flows and breccias
Tta	--	0	25	Bedded rhyolite ash-fall tuffs, sandstones, and conglomerate
Tco	--	0	670	Andesitic mudflows
Ta	--	0	60	Massive, flow–laminated andesite lava flows; 25–35% crystals
--	RT	0	150	Moderately to weakly welded rhyolite tuff; 25% crystals
--	DS	90	100	Weakly to moderately welded rhyolite tuff; 15–20% crystals
--	WW	0	170	Moderately to densely welded dacite tuff; 20–45% crystals
Tbt	--	0	5	Ash-fall and reworked bedded tuff
--	CW	0	250	Moderately to densely welded dacite tuff; 30–45% crystals
Tlf	--	0	296	Lacustrine limestone and fluvial siltstone, sandstone, and conglomerate
	WB	0	115	Weakly to moderately welded rhyolite tuff; 25% crystals
Twg	--	0	140	Andesite lava flows and flow breccias; 5–30% crystals

Mountain range to the east: West Range

Local Unit	Regional Unit	Minimum thickness, m	Maximum thickness, m	Lithology
Tfg	--	0	40	Poorly sorted boulder and cobble deposits
Tts	--	0	30	Sandstone, ash, shale, and pebble conglomerate; lacustrine limestone
--	SP	20	60	Densely welded rhyolite tuff; 10–15% crystals
Ttu	--	5	30	Tuffaceous sandstone and ash-fall tuff and conglomerate
--	IS	10	20	Densely welded trachydacite tuff; 10–15% crystals
Ttl	--	0	30	Tuffaceous sandstone and ash-fall tuff and conglomerate
Tr	--	40	60	Rhyolite lava dome; 1% crystals
--	LF	20	200	Weakly to densely welded dacite tuff; 20–28% crystals
--	DS	0	200	Densely welded rhyolite tuff; 20–25% crystals
Tns	--	30	60	Tuff, tuffaceous sandstone, and conglomerate
--	CW and (or) WW	0	130	Densely welded dacite tuff; 26–50% crystals
Ta	--	0	30	Andesite lava flows; 28% crystals

Compilation of thickness of Tertiary rocks

Mountain range to the west: North Pahroc Range

	Minimum thickness, m	Maximum thickness, m
Local units	0	2,109
Regional units	155	961
Total	155	3,070

Mountain range to the east: West Range

	Minimum thickness, m	Maximum thickness, m
Local units	75	280
Regional units	50	610
Total	125	890

Inferred thickness of volcanic rocks beneath valley axis, 50–800 m

[1]Local units have limited spatial extent within a single mapped quadrangle or mountain range; typically includes lava flows and Tertiary sedimentary rocks interbedded with tuff. Local units, from uppermost unit downward are: Tfg, Oldest fanglomerate; Tts, Tuffaceous sedimentary rocks; Tb, Basaltic flows; Tah, Andesite lava flows of Hamilton Spring; Tms, Andesite lava flows of Mustang Spring; Tta, Bedded tuff and andesitic conglomerate; Tco, Mudflows of Coal Spring; Ttu, Tuffaceous bedded rocks, upper; Ttl, Tuffaceous bedded rocks, lower; Tr, Rhyolite lava dome; Ta, Andesite lava flows; Tbt, Bedded tuff; Tlf, Lacustrine and fluvial sedimentary rocks; Tns, Sedimentary rocks above Wah Wah Springs Formation; Twg, Andesite lava flows of Wheatgrass Spring.

[2]Regional units occur in several quadrangles or mountain ranges. These volcanic-rock units are typically ash-flow tuffs. Regional units, from uppermost unit downward are: PF, Pahranagat Formation; CB, Bauers Tuff Member, Condor Canyon Formation; BT, Tuff member, Blawn Formation; SP, Shingle Pass Tuff; IS, Isom Formation; PC, Petroglyph Cliff Ignimbrite; LF, Lund Formation; RT, Rhyolitic tuff; DS, Tuff of Deadman Summit; WW, Wah Wah Springs Formation; CW, Cottonwood Wash Tuff; WB, Windous Butte Formation.

Table 2. Compilation of volcanic-rock thickness from mountain ranges flanking Muleshoe Valley

[There is no published reference for Tertiary stratigraphic thickness for the Schell Creek Range; thickness data for the Grassy Mountain/Fairview Range area from Best and others (1998); leaders (--), unit not present]

Description of geologic map units

Mountain range to the west: the southern part of the Schell Creek Range

Local Unit[1]	Regional Unit[2]	Minimum thickness, m	Maximum thickness, m	Lithology

The southern part of the Schell Creek Range, at the head of of Muleshoe Valley, includes a significant outcrop area of undocumented Tertiary volcanic rock on its east flank. However, further south in the Schell Creek Range, volcanic rocks are absent. The Grassy Mountain/Fairview Range area, on the east side of Muleshoe Valley, contains a considerable thickness of Tertiary volcanic rocks. Therefore, assuming that volcanic rock distribution was symmetric around Muleshoe Valley, thickness relations in the Grassy Mountain/Fairview Range area are used as a proxy for Tertiary volcanic rock thickness in Muleshoe Valley

Mountain range to the east: the Grassy Mountain/Fairview Range area

Local Unit	Regional Unit	Minimum thickness, m	Maximum thickness, m	Lithology
Tf	--	0	30	Partly consolidated sandstone, locally conglomeratic; mudflow breccia
Ts	--	0	80	Sandstone and conglomeratic sandstone; also limestone and ash-fall tuff
Tbm	--	0	60	Somewhat porphyritic, aphanitic mafic lava flows
--	BT	0	10	Weakly consolidated rhyolite tuff; 2–4% crystals
--	PF	0	230	Moderately welded rhyolite tuff; 15–35% crystals
--	CB	0	40	Densely welded rhyolite tuff; 3–5% crystals
Tr	--	0	200	Aphyric rhyolite lava flows
--	LC	0	75	Partly welded rhyolite tuff; 20% crystals
--	IS	10	20	Densely welded trachydacite tuff; 20% crystals
--	SPU	0	200	Moderately to densely welded rhyolite tuff; 15% crystals
--	SPL	0	200	Moderately to densely welded rhyolite tuff; 15% crystals
--	RAT	0	60	Moderately welded rhyolite tuff; 10% crystals
Tch	--	0	100	Flow-layered dacite lava flow; 15% crystals
--	RT	0	60	Weakly welded rhyolite tuff; 5% crystals
--	PC	0	70	Densely to moderately welded trachydacite tuff; 10% crystals
--	LF	0	1,000	Moderately to densely welded dacite tuff; 55% crystals
--	SK	0	600	Moderately to densely welded dacite tuff; 33% crystals
--	RST	0	30	Rhyolite tuff; 15% crystals
--	DS	0	380	Densely welded rhyolite tuff; 33% crystals
--	WW	0	120	Densely welded dacite tuff; 40% crystals
--	CW	12	280	Densely to moderately welded dacite tuff; crystal rich
--	WB	0	3	Partly welded rhyolite tuff
Ta	--	0	300	Altered, aphanitic andesite lava flows; abundant phenocrysts
Tb	--	0	30	Massive, altered, aphanitic rhyolite lava flows; 15% phenocrysts
--	SW	0	40	Moderately to weakly welded tuff; 40% crystals
Tls	--	0	20	Thinly bedded lacustrine limestone

Compilation of thickness of Tertiary rocks

Mountain range to the west: the southern part of the Schell Creek Range

	Minimum thickness, m	Maximum thickness, m
Local units	0	46
Regional units	144	1,113
Total	144	1,159

Mountain range to the east: the Grassy Mountain/Fairview Range area

	Minimum thickness, m	Maximum thickness, m
Local units	0	690
Regional units	22	3,418
Total	22	4,108

Inferred thickness of volcanic rocks beneath valley axis, 23–3,400 m

[1]Local units have limited spatial extent within a single mapped quadrangle or mountain range; typically includes lava flows and Tertiary sedimentary rocks interbedded with tuff. Local units, from uppermost unit downward are: Tf, Semi-consolidated alluvium; Ts, Sedimentary deposits; Tbm, Mafic lava flow member, Blawn Formation; Tr, Rhyolite lava flows; Tch, Lava flow of Chokecherry Spring; Ta, Andesitic lava flows; Tb, Rhyolite lava flow of Bailey Spring; Tls, Limestone.

[2]Regional units occur in several quadrangles or mountain ranges. These volcanic-rock units are typically ash-flow tuffs. Regional units, from uppermost unit downward are: BT, Tuff member, Blawn Formation; PF, Pahranagat Formation; CB, Bauers Tuff Member, Condor Canyon Formation; LC, Leach Canyon Formation; IS, Isom Formation; SPU, Upper member, Shingle Pass Tuff; SPL, Lower member, Shingle Pass Tuff; RAT, Rhyolitic tuff; RT, Tuff member, Ripgut Formation; PC, Petroglyph Cliff Ignimbrite; LF, Lund Formation; SK, Tuff of Silver King Well; RST, Tuff member, Ryan Spring Formation; DS, Tuff of Deadman Spring; WW, Wah Wah Springs Formation; CW, Cottonwood Wash Tuff; WB, Windous Butte Formation; SW, Tuff of Silverhorn Wash.

Table 3. Compilation of volcanic-rock thickness from mountain ranges flanking Cave Valley

[Thickness data for the Egan Range (near Shingle Pass) from Kellogg (1964), Best and Christiansen (1996), and Best, Christiansen, and others (1989); no published reference for Tertiary stratigraphic thickness for the Schell Creek Range; leaders (--), unit

Description of geologic map units

Mountain range to the west: Egan Range (near Shingle Pass)

Local Unit[1]	Regional Unit[2]	Minimum thickness, m	Maximum thickness, m	Lithology
sr	--	0	610	Fluviatile and tuffaceous sedimentary rocks
--	PF	20	21	Weak to moderately welded rhyolite tuff; 20% crystals
--	CB	0	10	Densely welded rhyolite tuff; 15% crystals
--	SPU	0	40	Moderately welded rhyolite tuff; 5–10% crystals
--	SPL	35	35	Moderately welded rhyolite tuff; 15–20% crystals
--	WW	29	60	Densely welded; dacite tuff; 35–40% crystals
--	CW	6	120	Weak to moderately welded crystal-rich dacite tuff
--	WB	90	165	Moderately to weakly welded rhyolite-dacite tuff; 15–30% crystals
dl		30	84	Flow-banded biotite dacite lava; locally glassy; 15–30% crystals
--	SC	0	120	Rhyolite tuff
tts	--			Soft, porous, laminated tuffs and tuffaceous sedimentary rocks
ssc	--	0	305	Conglomerate, sandstone, and clay
--	SHP	115	1,013	Lacustrine deposits; limestone, mudstone, and conglomerate

Mountain range to the east: the southern part of the Schell Creek Range

Local Unit	Regional Unit	Minimum thickness, m	Maximum thickness, m	Lithology

The Schell Creek Range, east of Cave Valley, includes a significant outcrop area of undocumented Tertiary volcanic rocks, mostly on its east flank. Also, the Grassy Mountain/Fairview Range area, to the southeast of Cave Valley contains a considerable thickness of Tertiary volcanic rock. Therefore, assuming that volcanic rock distribution was symmetric around Cave Valley, thickness relations in the Egan Range were used as a proxy for Tertiary volcanic rock thickness in Cave Valley.

Compilation of thickness of Tertiary rocks

Mountain range to the west: Egan Range (near Shingle Pass)

	Minimum thickness, m	Maximum thickness, m
Local units	30	999
Regional units	180	1,584
Total	325	2,583

Mountain range to the east: the southern part of the Schell Creek Range

	Minimum thickness, m	Maximum thickness, m
Local units	--	--
Regional units	--	--
Total	--	--

Inferred thickness of volcanic rocks beneath valley axis, 300–1,600 m

[1]Local units have limited spatial extent within a single mapped quadrangle or mountain range; typically includes lava flows and Tertiary sedimentary rocks interbedded with tuff. Sr, sedimentary rocks; dl, dacite lava; tts, tuffs and tuffaceous sedimentary rocks; ssc, Stinking Spring Conglomerate.

[2]Regional units occur in several quadrangles or mountain ranges. These volcanic-rock units are typically ash-flow tuffs. Regional units, from uppermost unit downward are: PF, Pahranagat Formation; CB, Bauers Tuff Member, Condor Canyon Formation; SPU, Upper member, Shingle Pass Tuff; SPL, Lower member, Shingle Pass Tuff; WW, Wah Wah Springs Formation; CW, Cottonwood Wash Tuff; WB, Windous Butte Formation; SC, Stone Cabin Formation; SHP, Sheep Pass Formation.

Table 4. Compilation of volcanic-rock thickness from mountain ranges flanking southern part of Lake Valley

[Thickness data for the Grassy Mountain/Fairview Range area and Bristol Range from Best and others (1998); thickness data for the Wilson Creek Range from Willis and others (1987) and Williams and others (1997); leaders (--), unit not present]

Description of geologic map units

Mountain range to the west: Grassy Mountain/Fairview Range area and Bristol Range[1]

Local Unit[2]	Regional Unit[3]	Minimum thickness, m	Maximum thickness, m	Lithology
Tf	--	0	30	Partly consolidated sandstone, locally conglomeratic; mudflow breccia
Tbm	--	0	60	Somewhat porphyritic, aphanitic mafic lava flows
--	BT	0	10	Weakly consolidated rhyolite tuff; 2–4% crystals
--	PF	0	230	Moderately welded rhyolite tuff; 15–35% crystals
--	CB	0	40	Densely welded rhyolite tuff; 3–5% crystals
Tr	--	0	200	Aphyric rhyolite lava flows
Ts	--	0	80	Sandstone and conglomeratic sandstone; also limestone and ash-fall tuff
--	LC	0	75	Partly welded rhyolite tuff; 20% crystals
--	IS	10	20	Densely welded trachydacite tuff; 20% crystals
--	SPU	0	200	Moderately to densely welded rhyolite tuff; 15% crystals
--	SPL	0	200	Moderately to densely welded rhyolite tuff; 15% crystals
--	RAT	0	60	Moderately welded rhyolite tuff; 10% crystals
Tch	--	0	100	Flow-layered dacite lava flow; 15% crystals
--	RF	0	60	Weakly welded rhyolite tuff; 5% crystals
--	PC	0	70	Densely to moderately welded trachydacite tuff; 10% crystals
--	LF	0	1,000	Moderately to densely welded dacite tuff; 55% crystals
--	SK	0	600	Moderately to densely welded dacite tuff; 33% crystals
--	RST	0	30	Rhyolite tuff; 15% crystals
--	DS	0	380	Densely welded rhyolite tuff; 33% crystals
--	WW	0	120	Densely welded dacite tuff; 40% crystals
--	CW	12	280	Densely to moderately welded dacite tuff; crystal rich
--	WB	0	3	Partly welded rhyolite tuff
Ta	--	0	300	Altered, aphanitic andesite lava flows; abundant phenocrysts
Tb	--	0	30	Massive, altered, aphanitic rhyolite lava flows; 15% phenocrysts
--	SW	0	40	Moderately to weakly welded tuff; 40% crystals

Mountain range to the east: Wilson Creek Range

Local Unit	Regional Unit	Minimum thickness, m	Maximum thickness, m	Lithology
Tal	--	0	50	Alluvial fan deposits; poorly sorted boulders and cobbles
Te	--	0	110	Thin bedded, lacustrine silt and sand; some sand, pebbles, and tephra
Tsr	--	0	250	Aphanitic rhyolite lava flows and domes; 10% crystals
--	SR	0	120	Porous volcaniclastic deposits; some sandstone
Tt	--	0	140	Porous pyroclastic and epiclastic deposits
Tbr	--	0	230	Aphanitic rhyolite lava flows and domes; 10-20% crystals
--	BT	0	450	Partly welded rhyolite tuff and epiclastic deposits
--	BG	0	80	Moderately welded tuff; 20% crystals
--	RC	0	1,050	Weakly to densely welded rhyolite tuff; 25-40% crystals
Ts	--	0	600	Fluvial-lacustrine conglomerate, sandstone, siltstone, and limestone
Tscl	--	0	300	Dacite and rhyolite lava flows and minor tuff; 25% crystals
Tn	--	150	250	Dacite to andesite lava flows; 20% crystals; locally vesicular
--	HH	20	150	Densely to moderately welded andesite tuff; 50% crystals
Tf	--	0	100	Rhyolite lava flows
Tlf	--	0	1,000	Trachyandesite to trachydacite flows; 5-25% crystals
--	AFT	0	150	Densely welded tuff; 25% crystals
Tl	--	0	130	Flow-layered lava flow
--	CB	10	200	Densely welded rhyolite tuff; 3-5% crystals
--	CS	0	200	Densely welded rhyolite tuff; 3-5% crystals
Tcg	--	0	50	Poorly-sorted boulder and cobble conglomerate
--	LC	200	400	Partly welded rhyolite tuff; 20% crystals
--	IS	0	200	Moderately to densely welded trachydacite; 20% crystals
--	RF	200	650	Partly to densely welded rhyolite tuff; crystal poor
--	LF	0	150	Moderately to densely welded dacite tuff; 30-40% crystals
--	WW	0	50	Densely welded dacite tuff; 40% crystals

Compilation of thickness of Tertiary rocks

Mountain range to the west: Grassy Mountain/Fairview Range area and Bristol Range

	Minimum thickness, m	Maximum thickness, m
Local units	0	800
Regional units	22	3,418
Total	22	4,218

Mountain range to the east: Wilson Creek Range

	Minimum thickness, m	Maximum thickness, m
Local units	150	3,210
Regional units	430	3,850
Total	580	7,060

Inferred thickness of volcanic rocks beneath valley axis, 22–3,400 m

[1]The Bristol Range, west of the southern part of Lake Valley, preserves no Tertiary volcanic rock. However, further north along the west side of the southern part of Lake Valley, the Grassy Mountain/Fairview Range area contains a considerable thickness of Tertiary volcanic rocks. Assuming that volcanic rock distribution was symmetric around the southern part of Lake Valley, thickness relations in the Grassy Mountain/Fairview Range proxy for Tertiary volcanic thicknesses along the west side of the southern part of Lake Valley.

[2]Local units have limited spatial extent within a single mapped quadrangle or mountain range; typically includes lava flows and Tertiary sedimentary rocks interbedded with tuff. Local units, from uppermost unit downward are: Tal, Tertiary fan alluvium; Te, Basin-fill deposits of Eagle Valley; Tsr, Rhyolite lava flow member, Steamboat Mountain Formation; Tt, Clastic rocks; Tf, Semiconsolidated alluvium; Tbr, Rhyolite lava flow member, Blawn Formation; Tbm, Mafic lava flow member, Blawn Formation; Tr, Rhyolite lava flows; Ts, Sedimentary deposits; Tscl, Lava-flows member, intermediate-composition rocks of Serviceberry Canyon; Tn, Lava flows of Ninemile Rocks; Tch, Lava flow of Chokecherry Spring; Tf, Rhyolite lava flow of Tobe Spring; Tlf, Latite lava flows; Tl, Lava flow; Tcg, Conglomerate; Ta, Andesitic lava flows; Tb, Rhyolite lava flow of Bailey Spring.

[3]Regional units occur in several quadrangles or mountain ranges. These volcanic-rock units are typically ash-flow tuffs. Regional units, from uppermost unit downward are: SR, Rhyolite tuff member, Steamboat Mountain Formation; BT, Tuff member, Blawn Formation; BG, tuff of Gold Springs, Blawn Formation; RC, Racer Canyon Tuff; HH, Harmony Hills Tuff; PF, Pahranagat Formation; AFT, Ash-flow tuff; CB, Bauers Tuff Member, Condor Canyon Formation; CS, Swett Tuff Member, Condor Canyon Formation; LC, Leach Canyon Formation; IS, Isom Formation; SPU, Upper member, Shingle Pass Tuff; SPL, Lower member, Shingle Pass Tuff; RAT, Rhyolitic tuff; RF, Tuff member, Ripgut Formation; PC, Petroglyph Cliff Ignimbrite; LF, Lund Formation; SK, Tuff of Silver King Well; RST, Tuff member, Ryan Spring Formation; DS, Tuff of Deadman Spring; WW, Wah Wah Springs Formation; CW, Cottonwood Wash Tuff; WB, Windous Butte Formation; SW, Tuff of Silverhorn Wash.

Table 5. Compilation of volcanic-rock thickness from mountain ranges flanking northern part of Lake Valley

[Thickness data for the central part of the Schell Creek Range from Van Loenen (1987); thickness data for the Fortification Range from Loucks and others (1989); leaders (--), unit not present]

Description of geologic map units

Mountain range to the west: central part of the Schell Creek Range

Local Unit[1]	Regional Unit[2]	Minimum thickness, m	Maximum thickness, m	Lithology

The central part of the Schell Creek Range, west of the north part of Lake Valley, includes a significant outcrop area of undocumented Tertiary volcanic rocks on its east flank. However, further north in the Schell Creek Range, volcanic rocks are scarce. The Grassy Mountain/Fairview Range area, southwest of Lake Valley, contains a considerable thickness of Tertiary volcanic rocks, as do the Wilson Creek and Fortification Ranges, to the southeast and east, respectively. Therefore, assuming that volcanic rock distribution was symmetric around the northern part of Lake Valley, thickness relations in the Fortification Range were used as a proxy for Tertiary volcanic rock thickness in the northern part of Lake Valley.

Mountain range to the east: Fortification Range

Local Unit	Regional Unit	Minimum thickness, m	Maximum thickness, m	Lithology
--	SP	0	15	Moderately welded rhyolite tuff; 15% crystals
--	IS	0	6	Moderately to densely welded trachytic tuff; 5–10% crystals
--	WW	0	270	Densely welded dacite tuff; 35–40% crystals
--	CW	0	220	Weak to moderately welded crystal-rich dacite tuff
Tea	--	0	240	Strongly porphyritic lava flows and flow breccias
--	WB	6	50	Moderately to weakly welded rhyolite to dacite tuff; 15–30% crystals
--	TD	0	670	Member d: weakly to moderately welded rhyolite tuff; 10–15% crystals
--	TC	0	300	Member c: weakly to densely welded rhyolite tuff; 10% crystals
Ttl	--	0	250	Member l: rhyolite lava; 21% crystals
--	TB	0	450	Member b: weakly welded rhyolite tuff; 8% crystals
--	TA	0	170	Member a: rhyolite air fall ash, surge, and ash flow tuff

Compilation of thickness of Tertiary rocks

Mountain range to the west: central part of the Schell Creek Range

	Minimum thickness, m	Maximum thickness, m
Local units	--	--
Regional units	--	--
Total	--	--

Mountain range to the east: Fortification Range

	Minimum thickness, m	Maximum thickness, m
Local units	0	490
Regional units	6	2,151
Total	6	2,641

Inferred thickness of volcanic rocks beneath valley axis, 6–2,100 m

[1]Local units have limited spatial extent within a single mapped quadrangle or mountain range; typically includes lava flows and Tertiary sedimentary rocks interbedded with tuff. Local units, from uppermost unit downward are: Tea, Andesite flow member, Escalante Desert Formation; Ttl, Lava flow member, formation of the Gouge Eye.

[2]Regional units occur in several quadrangles or mountain ranges. These volcanic-rock units are typically ash-flow tuffs. Regional units, from uppermost unit downward are: SP, Shingle Pass Tuff; IS, Isom Formation; WW, Wah Wah Springs Formation; CW, Cottonwood Wash Tuff; WB, Windous Butte Formation; TD, Member d, formation of the Gouge Eye; TC, Member c, formation of the Gouge Eye; TB, Member b, formation of the Gouge Eye; TA, Member a, formation of the Gouge Eye.

Table 6. Compilation of volcanic-rock thickness from mountain ranges flanking southern part of Spring Valley

[Thickness data for the Fortification Range from Loucks and others (1989); thickness data for the Wilson Creek Range and Limestone Hills from Willis and others (1987); leaders (--), unit not present]

Description of geologic map units

Mountain range to the west: Fortification Range

Local Unit[1]	Regional Unit[2]	Minimum thickness, m	Maximum thickness, m	Lithology
--	SP	0	15	Moderately welded rhyolite tuff; 15% crystals
--	IS	0	6	Moderately to densely welded trachytic tuff; 5–10% crystals
--	WW	0	270	Densely welded dacite tuff; 35–40% crystals
--	CW	0	220	Weak to moderately welded crystal-rich dacite tuff
Tea	--	0	240	Strongly porphyritic lava flows and flow breccias
--	WB	6	50	Moderately to weakly welded rhyolite to dacite tuff; 15–30%
--	TD	0	670	Member d: weakly to moderately welded rhyolite tuff; 10–15%
--	TC	0	300	Member c: weakly to densely welded rhyolite tuff; 10%
Ttl	--	0	250	Member l: rhyolite lava; 21% crystals
--	TB	0	450	Member b: weakly welded rhyolite flow tuff; 8% crystals
--	TA	0	170	Member a: rhyolite air fall ash, surge, and ash flow tuff

Mountain range to the east: Wilson Creek Range and Limestone Hills[3]

Local Unit	Regional Unit	Minimum thickness, m	Maximum thickness, m	Lithology
Tbr	--	0	200	Rhyolite lava flows and domes; 10–15% crystals; local vitrophyre
--	BT	0	200	Weakly to moderately welded rhyolite tuff, ash, and clastics; 10% crystals
Tba		0	135	Vesicular, aphyric to strongly porphyritic trachyandesite lava flows
--	BP	0	200	Moderately to weakly welded rhyolite tuff; 25–30% crystals
--	SP	0	100	Moderately to densely welded rhyolite tuff; 20% crystals
--	IS	0	300	Densely welded trachytic tuff; 10–12% crystals
--	RF	0	200	Moderately to densely welded rhyolite tuff; ~3% crystals
Tgs	--	0	130	Weak tuffaceous sandstone and siltstone and conglomeratic sandstone
--	RM	0	100	Densely welded rhyolite tuff; 10–15% crystals
--	RG	0	200	Moderately welded rhyolite tuff; crystal poor
--	WW	0	270	Densely welded dacite tuff; 40% crystals
--	CW	0	200	Dacite tuff; 40% crystals
Tea	--	0	200	Weakly porphyritic lava flows and flow breccias
--	WB	0	100	Moderately to weakly welded rhyolite tuff; 25% crystals

Compilation of thickness of Tertiary rocks

Mountain range to the west: Fortification Range

	Minimum thickness, m	Maximum thickness, m
Local units	0	490
Regional units	6	2,151
Total	6	2,641

Mountain range to the east: Wilson Creek Range and Limestone Hills

	Minimum thickness, m	Maximum thickness, m
Local units	0	665
Regional units	0	1,870
Total	0	2,535

Inferred thickness of volcanic rocks beneath valley axis, 0–1,900 m

[1]Local units have limited spatial extent within a single mapped quadrangle or mountain range; typically includes lava flows and Tertiary sedimentary rocks interbedded with tuff. Local units, from uppermost unit downward are: Tbr, Rhyolite member, Blawn Formation; Tba, Trachyandesite lava flow member, Blawn Formation; Tgs, Sedimentary member, Ripgut Formation; Tea, Andesite flow member, Escalante Desert Formation; Ttl, Lava flow member, formation of the Gouge Eye.

[2]Regional units occur in several quadrangles or mountain ranges. These volcanic-rock units are typically ash-flow tuffs. Regional units, from uppermost unit downward are: BT, Tuff member, Blawn Formation; BP, Tuff member of Rosencrans Peak, Blawn Formation; SP, Shingle Pass Tuff; IS, Isom Formation; RF, Ripgut Formation; RM, Mackleprang Tuff Member, Ryan Spring Formation; RG, Greens Canyon Tuff Member, Ryan Spring Formation; WW, Wah Wah Springs Formation; CW, Cottonwood Wash Tuff; WB, Windous Butte Formation; TD, Member d, formation of the Gouge Eye; TC, Member c, formation of the Gouge Eye; TB, Member b, formation of the Gouge Eye; TA, Member a, formation of the Gouge Eye.

[3]The Limestone Hills, directly east of the southern part of Spring Valley, are essentially devoid of Tertiary volcanic rocks; not factored into valley volcanic thickness estimates.

Table 7. Compilation of volcanic-rock thickness from mountain ranges flanking the central part of Spring Valley

[Thickness data for the northern part of Schell Creek Range from Drewes (1967); for the Snake Range from Whitebread (1969); leaders (--), unit not present]

Description of geologic map units

Mountain range to the west: northern part of Schell Creek Range

Local Unit[1]	Regional Unit[2]	Minimum thickness, m	Maximum thickness, m	Lithology
Tf	--	0	91	Fanglomerate
Td	--	0	365	Dacite lava; vitrophyre in part; 15-50% crystals
--	WW and (or) CW	0	610	Dacite tuff; vitrophyre in part
Tl	--	0	100	Latite; includes lava flows, tuff, and small intrusions
Tc	--	0	305	Conglomerate

Mountain range to the east: Snake Range

Local Unit	Regional Unit	Minimum thickness, m	Maximum thickness, m	Lithology
No Tertiary volcanic rocks present in northern and central parts of the Snake Range				
Southern part of the Snake Range:				
Tc	--	--	--	Conglomerate
--	WW and (or) CW	200	300	Dacite tuff; lower member not welded, upper member welded
Tco	--	--	--	Conglomerate

Compilation of thickness of Tertiary rocks

Mountain range to the west: northern part of Schell Creek Range

	Minimum thickness, m	Maximum thickness, m
Local units	0	861
Regional units	0	610
Total	0	1,471

Mountain range to the east: Snake Range

	Minimum thickness, m	Maximum thickness, m
Local units	--	--
Regional units	200	300
Total	200	300

Inferred thickness of volcanic rocks beneath valley axis, 0–600 m

[1]Local units have limited spatial extent within a single mapped quadrangle or mountain range; typically includes lava flows and Tertiary sedimentary rocks interbedded with tuff. Tf, fanglomerate; Tc, conglomerate; Td, dacite; Tl, latite; and Tco, conglomerate.

[2]Regional units occur in several quadrangles or mountain ranges. These volcanic-rock units are typically ash-flow tuffs. WW, Wah Wah Springs Formation; CW, Cottonwood Wash Tuff.

Table 8. Compilation of volcanic-rock thickness from mountain ranges flanking southern part of Hamlin Valley

[Thickness data for the southern part of the White Rock Mountains from Toth (1986) and Keith and others (1994); thickness data for the east-central Mountain Home Range from Best, Grant, and others (1987); leaders (--), unit not present]

Description of geologic map units

Mountain range to the west: the southern part of the White Rock Mountains

Local Unit[1]	Regional Unit[2]	Minimum thickness, m	Maximum thickness, m	Lithology
Tp	--	300	400	Weakly bedded clay and silt deposits
Tbr	--	0	230	Aphanitic rhyolite lava flows and domes; 10–20% crystals
--	BT	0	150	Weakly welded tuff; crystal poor
--	BG	0	20	Moderately welded tuff; 20% crystals
Tscl	--	0	300	Dacite and rhyolite lava flows and minor tuff; 25% crystals
--	HH	20	150	Densely to moderately welded andesite tuff; 50% crystals
Trt	--	0	100	Rhyolite lava flows
Tlf	--	0	130	Locally aphyric trachyandesite to trachydacite flows; 5–25% crystals
--	CB	0	30	Densely welded rhyolite tuff; 20% crystals
--	CS	10	15	Moderately to densely welded rhyolite tuff; 10% crystals
--	IS	0	400	Moderately to densely welded trachydacite tuff; 12% crystals
--	RF	0	650	Partly to densely welded rhyolite tuff; crystal poor
--	LF	0	100	Moderately to densely welded dacite tuff; 25–35% crystals
--	RG	50	1,400	Moderately welded rhyolite tuff; 10% crystals
--	WW	0	130	Densely welded dacite tuff; 40% crystals
--	CW	12	160	Densely to moderately welded dacite tuff; 40% crystals
Tea	--	0	350	Weakly porphyritic andesite lava flows
--	ST	0	150	Tuff; crystal rich

Mountain range to the east: the southern part of the Indian Peak Range

Local Unit	Regional Unit	Minimum thickness, m	Maximum thickness, m	Lithology
Tsr	--	0	500	Aphanitic rhyolite lava flows and domes; 0–30% crystals
Tbr	--	0	100	Rhyolite lava flows, domes, and dikes; 25% crystals
Tbm	--	0	500	Massive porphyritic mafic lava flows; 10% crystals
--	T	100	200	Pyroclastic and epiclastic rhyolite deposits
Tql	--	0	500	Flow-layered trachyandesite lava flows, domes, and plugs
--	CB	20	120	Densely welded rhyolite tuff; 10% crystals
Tds	--	0	250	Porphyritic dacite lava flow dome
--	IS	0	800	Densely welded trachydacite tuff; 15% crystals
Tha	--	0	250	Locally vesicular andesite lava flows; 25% crystals
Tla	--	0	400	Porphyritic andesite lava flows; also sandstone and tuff
--	LF	0	550	Moderately to densely welded dacite tuff; 45–50% crystals
Trr	--	0	200	Flow-layered rhyolite flows and flow domes; crystal poor
Tra	--	0	150	Porphyritic andesite lava flows
--	RM	50	500	Moderately welded rhyolite tuff; 20% crystals
--	WW	0	2,000	Densely welded dacite tuff; 40% crystals
--	CW	0	5	Densely welded dacite tuff; crystal rich
--	ST	0	200	Moderately welded tuff; 20–30% crystals

Compilation of thickness of Tertiary rocks

Mountain range to the west: the southern part of the White Rock Mountains

	Minimum thickness, m	Maximum thickness, m
Local units	300	1,510
Regional units	92	3,355
Total	392	4,865

Mountain range to the east: the southern part of the Indian Peak Range

	Minimum thickness, m	Maximum thickness, m
Local units	0	2,850
Regional units	170	4,375
Total	170	7,225

Inferred thickness of volcanic rocks beneath valley axis, 100–3,500 m

[1]Local units have limited spatial extent within a single mapped quadrangle or mountain range; typically includes lava flows and Tertiary sedimentary rocks interbedded with tuff. Local units, from uppermost unit downward are: Tp, Panaca Formation; Tsr, Rhyolite lava flow member, Steamboat Mountain Formation; Tbr, Rhyolite lava flow member, Blawn Formation; Tbm, Mafic lava flow member, Blawn Formation; Tql, Quartz latite; Tds, Dacite of Spanish George Spring; Tha, Hornblende andesite lava flows; Tla, Andesite member, Lund Formation; Tscl, Lava flows member, intermediate-composition rocks of Serviceberry Canyon; Trr, Rhyolite flow member, Ryan Spring Formation; Tra, Andesite flow member, Ryan Spring Formation; Trt, Rhyolite lava flow of Tobe Spring; Tlf, Latite lava flows; Tea, Andesite flow member, Escalante Desert Formation.

[2]Regional units occur in several quadrangles or mountain ranges. These volcanic-rock units are typically ash-flow tuffs. Regional units, from uppermost unit downward are: BT, Tuff member, Blawn Formation; BG, tuff of Gold Springs, Blawn Formation; T, Rhyolitic tuffs and related volcaniclastic deposits; HH, Harmony Hills Tuff; CB, Bauers Tuff Member, Condor Canyon Formation; CS, Swett Tuff Member, Condor Canyon Formation; IS, Isom Formation; RF, Tuff member, Ripgut Formation; RM, Mackleprang Tuff Member, Ryan Spring Formation; LF, Lund Formation; RG, Greens Canyon Tuff Member, Ryan Spring Formation; WW, Wah Wah Springs Formation; CW, Cottonwood Wash Tuff; ST, Sawtooth Peak Formation.

Table 9. Compilation of volcanic-rock thickness from mountain ranges flanking northern part of Hamlin Valley

[Thickness data for the northern part of the White Rock Mountains from Best, Toth, and others (1989); thickness data for the east-central Mountain Home Range from Hintze (1986) and Hintze and Best (1987); leaders (--), unit not present]

Description of geologic map units

Mountain range to the west: the northern part of the White Rock Mountains

Local Unit[1]	Regional Unit[2]	Minimum thickness, m	Maximum thickness, m	Lithology
Tp	--	--	--	Tuffaceous mudstone, siltstone, and fine-grained sandstone;
Ts	--	0	1300	Weakly consolidated fluvial and alluvial deposits
Tbr	--	0	300	Rhyolite lava flows and domes; 10–15% crystals; local vitrophyre
--	BT	50	120	Moderately welded rhyolite tuff, ash, and volcaniclastics;
Tba	--	0	80	Vesicular, aphanitic trachyandesite lava flows; 15% crystals
--	BP	0	150	Moderately welded rhyolite tuff; 25–30% crystals
--	CB	0	80	Densely welded rhyolite tuff; 15% crystals
--	CS	10	15	Moderately to densely welded rhyolite tuff; 10% crystals
--	IS	10	350	Moderately to densely welded trachytic tuff; 10–12% crystals
Tif	--	0	100	Lava flows; 15% crystals
--	RF	0	600	Moderately to densely welded rhyolite tuff; ~3% crystals
--	LF	0	600	Densely welded dacite tuff; 40% crystals
--	RM	0	60	Densely welded rhyolite tuff; 10–15% crystals
--	RG	600	1,400	Densely welded rhyolite tuff; 10% crystals
--	WW	0	600	Densely welded dacite tuff; 40% crystals
--	CW	0	200	Dacite tuff; 40% crystals
--	EL	0	100	Moderately to densely welded rhyolite tuff; 10–15% crystals
Tea	--	0	30	Weakly porphyritic lava flows and flow breccias

Mountain range to the east: east-central Mountain Home Range

Local Unit	Regional Unit	Minimum thickness, m	Maximum thickness, m	Lithology
Tcg	--	0	600	Weakly cemented conglomerate and sandstone
--	LF	0	600	Densely welded dacite tuff; 40% crystals
--	WW	0	300	Weakly to densely welded dacite tuff; 42% crystals
--	CW	275	400	Weak to densely welded dacite tuff; 40% crystals
--	EB	0	10	Weakly consolidated tuff and tuffaceous sediment and conglomerate
--	EL	0	90	Moderately to densely welded rhyolite tuff; 12% crystals
Tea		0	12	Weakly porphyritic andesite lava flows
--	ST	0	50	Weakly welded tuff; 50% crystals
Ts	--	0	30	Cobbles and boulders in weakly consolidated tuffaceous matrix

Compilation of thickness of Tertiary rocks

Mountain range to the west: the northern part of the White Rock Mountains

	Minimum thickness, m	Maximum thickness, m
Local units	0	1,810
Regional units	670	4,275
Total	670	6,085

Mountain range to the east: east-central Mountain Home Range

	Minimum thickness, m	Maximum thickness, m
Local units	0	642
Regional units	275	1,450
Total	275	2,092

[3]Inferred thickness of volcanic rocks beneath valley axis, 3–3,000 m

[1]Local units have limited spatial extent within a single mapped quadrangle or mountain range; typically includes lava flows and Tertiary sedimentary rocks interbedded with tuff. Local units, from uppermost unit downward are: Tp, Panaca Formation; Ts, Sandstone and conglomerate; Tcg, Conglomerate; Tbr, Rhyolite member, Blawn Formation; Tba, Trachyandesite lava flow member, Blawn Formation; Tif, Lava flow member, Isom Formation; Tea, Andesite flow member, Escalante Desert Formation; Ts, Sedimentary rocks.

[2]Regional units occur in several quadrangles or mountain ranges. These volcanic-rock units are typically ash-flow tuffs. Regional units, from uppermost unit downward are: BT, Tuff member, Blawn Formation; BP, Tuff member of Rosencrans Peak, Blawn Formation; CB, Bauers Tuff Member, Condor Canyon Formation; CS, Swett Tuff Member, Condor Canyon Formation; IS, Isom Formation; RF, Ripgut Formation; LF, Lund Formation; RM, Mackleprang Tuff Member, Ryan Spring Formation; RG, Greens Canyon Tuff Member, Ryan Spring Formation; WW, Wah Wah Springs Formation; CW, Cottonwood Wash Tuff; EB, Beers Spring Member, the Escalante Desert Formation; EL, Lamerdorf Tuff Member, Escalante Desert Formation; ST, Sawtooth Peak Formation.

[3]Thicknesses possibly overstated. Truly adjacent ranges (Limestone Hills, the southern part of the Snake Range, and the western part of the Mountain Home Range) seem to contain only minor amounts of Tertiary rocks.

Table 10. Compilation of volcanic-rock thickness from mountain ranges flanking Snake Valley

[Thickness data for the Snake Range from Hose and others (1976), for the Confusion Range and Burbank Hills from Hose (1965) and Hintze (1974a); leaders (--), unit not present]

Description of geologic map units

Mountain range to the west: Snake Range					Mountain range to the east: Confusion Range and Burbank Hills				
Local Unit[1]	Regional Unit[2]	Minimum thickness, m	Maximum thickness, m	Lithology	Local Unit	Regional Unit	Minimum thickness, m	Maximum thickness, m	Lithology
No Tertiary volcanic rocks present in northern, central, and southeastern parts of the Snake Range					Very minimal thickness of Tertiary volcanic rock in Confusion Range				
					Hintze (1974a) suggests 0–15 m of Cottonwood Wash Tuff and 15 m of Tunnel Spring Tuff				

Compilation of thickness of Tertiary rocks

Mountain range to the west: Snake Range			Mountain range to the east: Confusion Range and Burbank Hills		
	Minimum thickness, m	Maximum thickness, m		Minimum thickness, m	Maximum thickness, m
Local units	--	--	Local units	--	--
Regional units	--	--	Regional units	0	30
Total	--	--	Total	0	30

Inferred thickness of volcanic rocks beneath valley axis, 0–30 m

Thickness of Tertiary volcanic rock in Snake Valley and Ferguson Desert is probably 0 to at most 50 m.
Although the Cottonwood Wash Tuff and Wah Wah Springs Formation are likely to have been deposited in the Snake Valley and Ferguson Desert, their scant thicknesses in the adjacent ranges (southern part of Snake Range, northern part of Mountain Home Range, Burbank Hills, and Confusion Range) suggests that these rock units were mostly eroded away, presumably prior to Snake Valley graben formation.

[1]Local units have limited spatial extent within a single mapped quadrangle or mountain range; typically includes lava flows and Tertiary sedimentary rocks interbedded with tuff.

[2]Regional units occur in several quadrangles or mountain ranges. These volcanic-rock units are typically ash-flow tuffs.

Table 11. Compilation of volcanic-rock thickness from mountain ranges flanking southern part of Pine Valley

[Thickness data for Indian Peak Range from Best, Grant, and others (1987) and Best, Hintze, and Homes (1987); thickness data for the southern part of the Wah Wah Mountains from Best, Morris, and others (1987) and Abbott and others (1983); leaders (--), uni

Description of geologic map units

Mountain range to the west: Indian Peak Range					Mountain range to the east: the southern part of the Wah Wah Mountains				
Local Unit[1]	Regional Unit[2]	Minimum thickness, m	Maximum thickness, m	Lithology	Local Unit	Regional Unit	Minimum thickness, m	Maximum thickness, m	Lithology
Ts	--	110	420	Poorly cemented fluvial-lacustrine deposits	Tbrp	--	0	100	Porphyritic basaltic trachyandesite lava flows; 10% crystals
Tsr	--	0	500	Massive to flow-layered rhyolite lava flows; 30% crystals	Tbra	--	0	100	Aphyric, vesicular trachyandesite lava flows
Tbr	--	--	--	Flow-layered porphyritic rhyolite lava flows and domes; 10% crystals	Tsr	--	0	500	Massive to flow-layered rhyolite lava flows; 30 percent crystals
Tbm	--	0	500	Massive to slight vesicular porphyritic mafic lava flows; 10% crystals	Tbr	--	0	400	Flow-layered porphyritic rhyolite lava flows and domes; 10% crystals
--	CB	3	25	Densely welded rhyolite tuff; 10–15% crystals	--	BT	0	400	Weakly welded tuff; 20% crystals; also intercalated volcanic sandstone
Tds	--	0	250	Porphyritic dacite lava dome	Tbm	--	0	200	Vesicular trachyandesite lava flows; 30% crystals
--	IS	0	110	Densely welded trachydacite tuff; 10–15% crystals	--	BTG	0	150	Weakly welded tuff; 20% crystals; contains a of trace garnet
Tha	--	0	250	Locally vesicular andesite lava flows; 25% crystals	Tlt	--	100	200	Crystal-poor tuff and water laid deposits
Tla	--	0	400	Porphyritic andesite lava flows; also sandstone and tuff	--	CB	0	30	Densely welded rhyolite tuff; 10–15% crystals
--	LF	55	600	Weakly to densely welded dacite tuff; 30–45% crystals	--	IS	10	150	Densely welded trachydacite tuff; 10% crystals
Trr	--	0	200	Flow-layered lava flows and flow domes; crystal poor	--	WP	0	200	Weakly welded tuff; 30–45% crystals
Tra	--	0	150	Nonvesicular, porphyritic andesite lava flows	--	LF	0	300	Weakly to densely welded dacite tuff; 30–45% crystals
--	RM	0	70	Moderately welded rhyolite tuff; 20% crystals	--	WW	0	460	Densely welded dacite tuff; 40–50% crystals
--	RG	0	500	Weakly welded tuff; crystal poor	--	CW	0	20	Densely welded dacite tuff; 41% crystals
--	WW	0	520	Densely welded dacite tuff; 40–50% crystals	Teb	--	0	40	Volcanic sandstone; also, poorly cemented pebble to cobble gravel
--	CW	0	305	Densely welded dacite tuff; 41% crystals	--	EL	0	650	Densely welded dacite tuff; 40–50% crystals
--	EL	100	170	Densely welded rhyolite tuff; 11–18% crystals	Tea	--	0	360	Nonvesicular, porphyritic andesite lava flows
Tea	--	0	60	Nonvesicular, porphyritic andesite lava flows	Ter	--	0	250	Densely welded dacite tuff; 41% crystals
Ter	--	--	--	Flow-layered rhyolite lava; 2% crystals	--	EM	0	300	Weakly welded tuff; crystal poor
--	EM	270	500	Weakly welded tuff; crystal poor	Toa	--	--	--	Nonvesicular andesite lava
--	ST	0	250	Moderately welded tuff; 25% crystals	Tcg	--	0	80	Pebble to boulder conglomerate

Compilation of thickness of Tertiary rocks

Mountain range to the west: Indian Peak Range			Mountain range to the east: the southern part of the Wah Wah Mountains		
	Minimum thickness, m	Maximum thickness, m		Minimum thickness, m	Maximum thickness, m
Local units	110	2,730	Local units	100	2,230
Regional units	428	3,050	Regional units	10	2,660
Total	538	5,780	Total	110	4,890

Inferred thickness of volcanic rocks beneath valley axis, 10–2,800 m

[1]Local units have limited spatial extent within a single mapped quadrangle or mountain range; typically includes lava flows and Tertiary sedimentary rocks interbedded with tuff. Local units, from uppermost unit downward are: Ts, Volcanic sandstone and conglomerate; Tbrp, Porphyritic member, formation of Brimstone Reservoir; Tbra, Aphyric member, formation of Brimstone Reservoir; Tsr, Rhyolite lava flow member, Steamboat Mountain Formation; Tbr, Rhyolite lava flow member, Blawn Formation; Tbm, Mafic lava flow member, Blawn Formation; Tlt, Lapilli tuff; Tds, Dacite of Spanish George Spring; Tha, Hornblende andesite lava flows; Tla, Andesite member, Lund Formation; Trr, Rhyolite flow member, Ryan Spring Formation; Tra, Andesite flow member, Ryan Spring Formation; Teb, Beers Spring Member, Escalante Desert Formation; Tea, Andesite flow member, Escalante Desert Formation; Ter, Rhyolite flow member, Escalante Desert Formation; Toa, Andesitic lava flows; Tcg, Conglomerate.

[2]Regional units occur in several quadrangles or mountain ranges. These volcanic-rock units are typically ash-flow tuffs. Regional units, from uppermost unit downward are: BT, Tuff member, Blawn Formation; BTG, Garnet-bearing tuff member, Blawn Formation; CB, Bauers Tuff Member, Condor Canyon Formation; IS, Isom Formation; WP, Wallaces Peak Member, Needles Range Formation; LF, Lund Formation; RM, Mackleprang Tuff Member, Ryan Spring Formation; RG, Greens Canyon Tuff Member, Ryan Spring Formation; WW, Wah Wah Springs Formation; CW, Cottonwood Wash Tuff; EL, Lamerdorf Tuff Member, Escalante Desert Formation; EM, Tuff of Marsden Spring, Escalante Desert Formation; ST, Sawtooth Peak Formation.

Table 12. Compilation of volcanic-rock thickness from mountain ranges flanking northern part of Pine Valley

[Thickness data for central Mountain Home Range from Hintze (1981), Best and Hintze (1980), and Best, Hintze, and Homes (1987); thickness data for the northern part of the Wah Wah Mountains from Wheeler (1980) and Hintze (1974b); leaders (--), unit not pre

Description of geologic map units

Mountain range to the west: central Mountain Home Range

Local Unit[1]	Regional Unit[2]	Minimum thickness, m	Maximum thickness, m	Lithology
Ts	--	110	420	Partly consolidated clayey, sandy, and conglomeratic deposits
Tc	--	0	20	Unconsolidated conglomerate and tuffaceous sandstone
--	CB	0	6	Densely welded rhyolite tuff; 20% crystals
--	IS	0	6	Densely welded trachytic tuff; 10% crystals
--	LF	30	112	Moderately welded dacite tuff; 39% crystals
--	WW	0	370	Moderately to densely welded dacite tuff; 42% crystals
--	CW	90	460	Weak to densely welded dacite tuff; 42% crystals
--	EB	24	55	Weakly consolidated tuff and tuffaceous sediment and conglomerate
--	EL	0	43	Moderately to densely welded rhyolite tuff; 12% crystals
Tea	--	0	46	Massive phenocryst-poor andesite lava
--	ST	0	61	Friable, porous, weakly welded tuff; 33–50% crystals

Mountain range to the east: the northern part of the Wah Wah Mountains

Local Unit	Regional Unit	Minimum thickness, m	Maximum thickness, m	Lithology
Tb	--	0	500	Volcanic (?) landslide-related breccia masses
Tc	--	0	50	Conglomerate and tuffaceous sandstone
Tba	--	0	150	Mafic, aphanitic, vesicular lava flows; some phenocrysts
--	BT	0	30	Moderately welded rhyolite tuff, ash, and clastics; 10% crystals
--	IS	0	28	Densely welded trachytic tuff; 10% crystals
--	WP	0	84	Tuff
--	LF	0	70	Moderately welded dacite tuff; 42% crystals
--	WW	0	116	Moderately to densely welded dacite tuff; 45% crystals
--	CW	20	40	Moderately welded dacite tuff; 37% crystals
--	TS	0	61	Rhyolite tuff
Tp	--	0	152	Andesite lava and lava flow domes; also dacite tuff

Compilation of thickness of Tertiary rocks

Mountain range to the west: central Mountain Home Range

	Minimum thickness, m	Maximum thickness, m
Local units	110	486
Regional units	144	1,113
Total	254	1,599

Mountain range to the east: the northern part of the Wah Wah Mountains

	Minimum thickness, m	Maximum thickness, m
Local units	0	302
Regional units	20	979
Total	20	1,281

Inferred thickness of volcanic rocks beneath valley axis, 20–1,100 m

[1]Local units have limited spatial extent within a single mapped quadrangle or mountain range; typically includes lava flows and Tertiary sedimentary rocks interbedded with tuff. Local units, from uppermost unit downward are: Tb, Breccia; Ts, Sedimentary deposits; Tc, Conglomerate; Tba, Mafic flow member, Blawn Formation; Tea, Andesite flow member, Escalante Desert Formation; Tp, Pre-Tunnel Spring volcanic rocks.

[2]Regional units occur in several quadrangles or mountain ranges. These volcanic-rock units are typically ash-flow tuffs. Regional units, from uppermost unit downward are: BT, Tuff member, Blawn Formation; CB, Bauers Tuff Member, Condor Canyon Formation; IS, Isom Formation; WP, Wallaces Peak Member, Needles Range Formation; LF, Lund Formation; WW, Wah Wah Springs Formation; CW, Cottonwood Wash Tuff; TS, Tunnel Spring Tuff; EB, Beers Springs Member, the Escalante Desert Formation; EL, Lamerdorf Tuff Member, Escalante Desert Formation; ST, Sawtooth Peak Formation.

Table 13. Compilation of volcanic-rock thickness from mountain ranges flanking Wah Wah Valley

[Thickness data for the southern part of the Wah Wah Mountains from Abbott and others (1983) and Wheeler (1980); thickness data for the San Francisco Mountains from Best, Lemmon, and Morris (1989); leaders (--), unit not present]

Description of geologic map units

Mountain range to the west: the southern part of the Wah Wah Mountains

Local Unit[1]	Regional Unit[2]	Minimum thickness, m	Maximum thickness, m	Lithology
Tbrp	--	0	100	Porphyritic basaltic trachyandesite lava flows; 10% crystals
Tbra	--	0	100	Aphyric, vesicular trachyandesite lava flows
Tbr	--	0	400	Flow-layered porphyritic rhyolite lava flows and domes; 10% crystals
--	BT	0	400	Weakly welded tuff; 20% crystals; also intercalated volcanic sandstone
Tbm	--	0	200	Vesicular trachyandesite lava flows; 30% crystals
	BTG	0	150	Weakly welded tuff; 20% crystals; contains a of trace garnet
Tlt	--	--	--	Crystal-poor tuff and water laid deposits
--	CB	0	30	Densely welded rhyolite tuff; 10–15% crystals
--	IS	0	28	Densely welded trachydacite tuff; 10% crystals
--	WP	0	200	Weakly welded tuff; 30–45% crystals
--	LF	350	500	Weakly to densely welded dacite tuff; 30–45% crystals
--	WW	0	460	Densely welded dacite tuff; 30–45% crystals
--	CW	0	20	Densely welded dacite tuff; 30–45% crystals
Teb	--	0	40	Volcanic sandstone; also, poorly cemented pebble to cobble gravel
	EL	0	650	Densely welded rhyolite tuff; 10–15% crystals
Tela	--	--	--	Nonvesicular, aphanitic to crystal poor andesite lava flows
	EM	0	70	Weakly welded tuff; crystal poor
Toa	--	--	--	Nonvesicular andesite lava
Tcg	--	0	80	Pebble to boulder conglomerate

Mountain range to the east: San Francisco Mountains

Local Unit	Regional Unit	Minimum thickness, m	Maximum thickness, m	Lithology
Tdf	--	0	100	Cobble to boulder volcanic debris flow deposits
Tsr	--	--	--	Vesicular, porphyritic rhyolite lava flows and domes
Tsb	--	0	100	Aphyric to porphyritic, vesicular basalt lava flows
Tbr	--	--	--	Flow–layered porphyritic rhyolite lava flows and domes; 20–30% crystals
--	BT	0	650	Weakly welded tuff; 20% crystals; also intercalated volcanic sandstone
Tbm	--	0	200	Vesicular trachyandesite lava flows; 25% crystals
Tsp	--	0	1,000	Flow-layered trachydacite lava flows: 33% crystals
--	CB	0	18	Densely welded rhyolite tuff; 10% crystals
--	IS	0	5	Densely welded trachydacite tuff; 10% crystals
--	TCT	0	200	Densely to moderately welded tuff; 40% crystals
--	LF	0	300	Densely welded dacite tuff; 40% crystals
--	WW	0	250	Densely welded dacite tuff; 40% crystals
--	CW	0	10	Densely welded dacite tuff; 30–45% crystals
--	EL	0	200	Moderately welded tuff; 15% crystals
Ths	--	0	700	Porphyritic andesite to dacite lava flows; 10% crystals
Tsh	--	0	600	Nonvesicular, andesite lava flows; 20% crystals
Thr	--	0	10	Pebble, cobble, and boulder conglomerate; siltstone to shale matrix

Compilation of thickness of Tertiary rocks

Mountain range to the west: the southern part of the Wah Wah Mountains

	Minimum thickness, m	Maximum thickness, m
Local units	0	920
Regional units	350	2,328
Total	350	3,248

Mountain range to the east: San Francisco Mountains

	Minimum thickness, m	Maximum thickness, m
Local units	0	2,710
Regional units	0	1,633
Total	0	4,343

Inferred thickness of volcanic rocks beneath valley axis, 0–1800 m

[1]Local units have limited spatial extent within a single mapped quadrangle or mountain range; typically includes lava flows and Tertiary sedimentary rocks interbedded with tuff. Local units, from uppermost unit downward are: Tdf, Volcanic debris flow; Tbrp, Porphyritic member, formation of Brimstone Reservoir; Tbra, Aphyric member, formation of Brimstone Reservoir; Tsr, Rhyolite lava-flow member, Steamboat Mountain Formation; Tsb, Basalt lava-flow member, Steamboat Mountain Formation; Tbr, Rhyolite lava flow member, Blawn Formation; Tbm, Mafic lava flow member, Blawn Formation; Tlt, Lapilli tuff; Tsp, Quartz latite of Squaw Peak; Teb, Beers Spring Member, the Escalante Desert Formation; Tela, Andesite in Lamerdorf Tuff Member, Escalante Desert Formation; Toa, Andesitic lava flows; Ths, Horn Silver Andesite; Tsh,Andesite of Shauntie Hills; Tcg, Conglomerate; Thr, Conglomerate of High Rock Pass area.

[2]Regional units occur in several quadrangles or mountain ranges. These volcanic-rock units are typically ash-flow tuffs. Regional units, from uppermost unit downward are: BT, Tuff member, Blawn Formation; BTG, Garnet-bearing tuff member, Blawn Formation; CB, Bauers Tuff Member, Condor Canyon Formation; IS, Isom Formation; WP, Wallaces Peak Member, Needles Range Formation; TCT, Three Creeks Tuff Member, Bullion Canyon Volcanics; LF, Lund Formation; WW, Wah Wah Springs Formation; CW, Cottonwood Wash Tuff; EL, Lamerdorf Tuff Member, Escalante Desert Formation; EM, Tuff of Marsden Spring, Escalante Desert Formation.