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Chapter 4

Quaternary volcanism in the western conterminous United States

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INTRODUCTION

This discussion of Quaternary volcanism in the western conterminous United States in part is similar to our earlier paper (Smith and Luedke, 1984) concerned with the late Cenozoic volcanism for the same region. One important difference between the two papers is the much shorter geologic time interval covered here (about the last 1.6 m.y.); in contrast, our earlier paper considered volcanism for a time span covering about the last 16 m.y. Both this and our earlier paper are based on a comprehensive study utilizing hundreds of references and five maps compiled and published in the U.S. Geological Survey Miscellaneous Investigations Series (Maps I-1091-A through E) at the scale of 1:1,000,000 (Luedke and Smith, 1978a, 1978b, 1981, 1982, and 1983). For compilation purposes, the volcanic rocks were grouped into five major types based primarily on their known or assumed silica content; the ages of the volcanic rocks arbitrarily were divided into three time frames of about 5 m.y. each, and the distribution and extent of volcanic fields were shown with and without vents. The information from those five maps, excluding vent data, was combined into a composite map at the scale of 1:2,500,000 (Luedke and Smith, 1984) thereby providing an overall data base for late Cenozoic volcanism.

It is not the intent of this brief review of Quaternary volcanism to discuss major volcano-tectonic or magmatic events, particularly considering the relatively short geologic time period. Such events, well underway prior to, but continuing into and during, the Quaternary, have been more fully treated by Armstrong (1978), Best and Hamblin (1978), Christiansen and Lipman (1972), Christiansen and McKee (1978), Eaton (1979), and Lipman (1980), to list a few. This chapter, therefore, focuses on brief descriptions of the volcanic centers in their respective regions, in which eruptive activity took place within the Quaternary, updating through cited literature areas where recent studies have been made.

Igneous rocks related to Quaternary volcanism in the western conterminous United States are predominantly extrusive but include, locally, their shallow intrusive equivalents. These extrusive rocks are principally lava flows of mafic composition but locally consist of lavas, debris, and ash flows of intermediate to silicic compositions. Source vents for much of the Quaternary volcanic rocks are generally known except where obscured by younger deposits, and generally reflect the dominant compositions of the eruptive products, i.e., cinder and/or spatter cones usually are associated with mafic rocks, composite volcanoes with mafic to intermediate rocks, and domes and dome-flows with intermediate to silicic rocks.

Following Smith and Luedke (1984), we have used the term volcanic locus to designate volcanic vents or groups of vents that define spatial and/or temporal units of volcanism, conventionally referred to as volcanic fields or centers where well-defined. The term locus has a slightly more specific connotation in that it outlines only the area of distribution of known vents in a volcanic field to more accurately portray the area of magmatic and thermal influence in the subsurface.

PRE-QUATERNARY VOLCANISM

Quaternary volcanism within the western conterminous U.S. must be discussed within the context of the late Cenozoic volcanism beginning about 16 or 17 Ma. About that time, following a short period of relative volcanic and tectonic inactivity (McKee and others, 1970), a widespread change in the style of volcanism occurred over much of the western conterminous U.S., including a compositional change from predominantly calcalkaline intermediate-composition volcanic rocks and associated differentiates (Lipman and others, 1972) to fundamentally mafic volcanic rocks (Christiansen and Lipman, 1972). Examples of the latter style of volcanism are the large Miocene basaltic fields such as the Columbia River Plateau in Oregon, Washington, and Idaho (Fig. 1) and the volcanic plateaus of southeastern Oregon and adjacent parts of California and Nevada. Many other separate smaller areas of dominantly basaltic volcanism also are found throughout the western states. There were, in addition, several predominantly andesitic regions such as the western Cascades of Oregon, the Blue Mountains in east-central Oregon, and exten-

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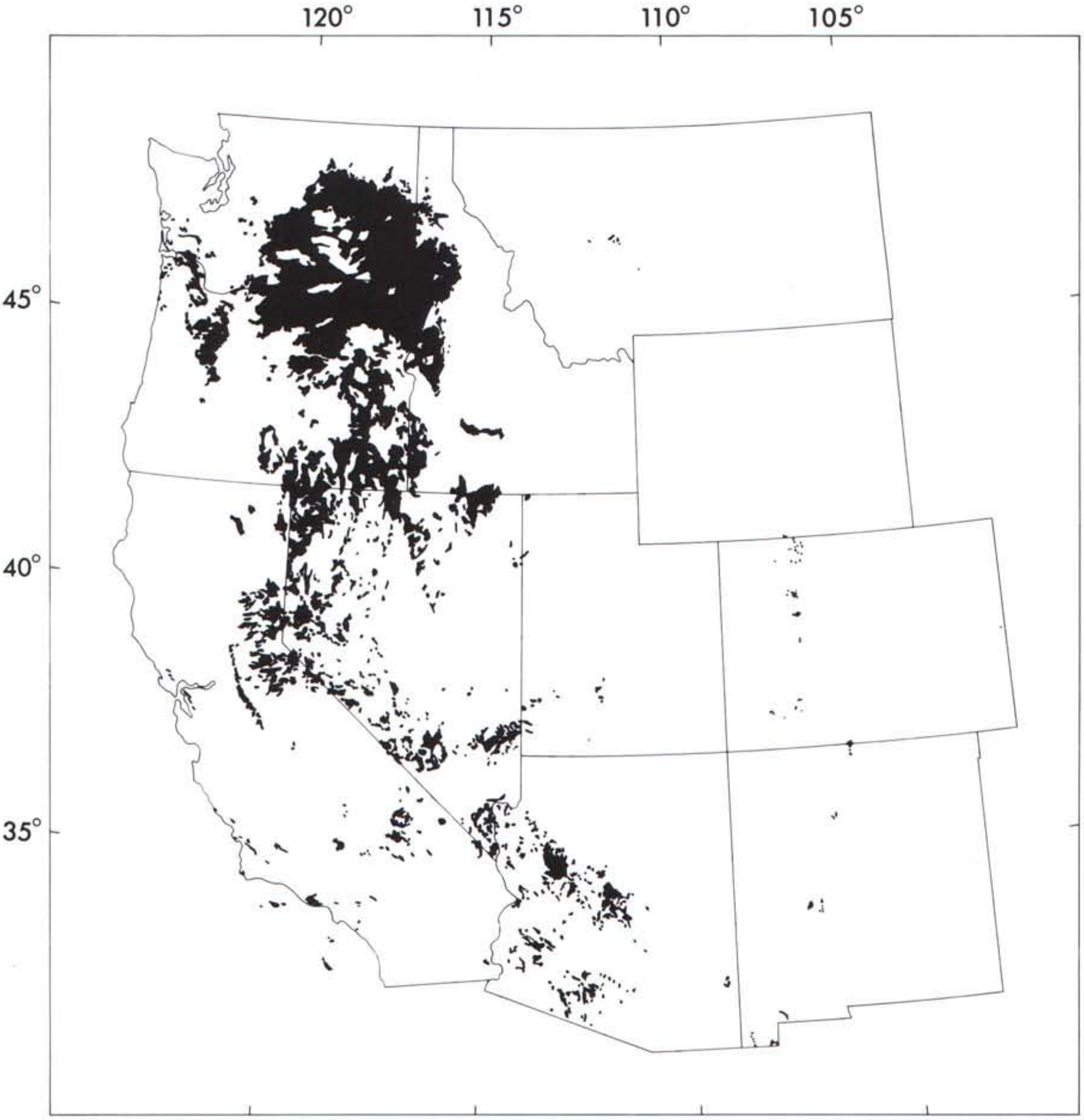

Figure 1. Map showing the distribution of upper Cenozoic volcanic rocks of all compositions extruded 10 to 16 Ma.

sive fields in the northern Sierra Nevada of California and adjacent Nevada. Silicic volcanism was represented by two notable ash-flow tuff and related caldera centers in southeastern Nevada (Timber Mountain and Kane Wash volcanic centers) and an extensive flow and ash-flow tuff field across northern Nevada and adjacent parts of Oregon and Idaho. Many of the volcanic loci for the rocks in this older time frame of 10 to 16 Ma either are obscure or appear to be randomly scattered.

Volcanic rocks of the 5 to 10 Ma period (Smith and Luedke, 1984), although not quite as extensive or voluminous as the eruptions in the previous time period, nevertheless covered large areas with mafic rocks in northeast California–southern Oregon (Fig. 2), northern Nevada–southwestern Idaho, and areas flanking the Colorado Plateau on the southwest and south. Rocks of intermediate composition, probably formerly more extensive than currently exposed, are found along the western flanks of the Cascade Range in Oregon, the Bodie Hills region of California-Nevada, and coastal valleys and ranges of California north and south of the San Francisco Bay area. Silicic rocks consisting of both lava flows and ash-flow tuffs are quite extensive in south-central Oregon, and southwestern and northeastern Idaho. During this 5 to 10 Ma period, volcanic loci became fixed essentially

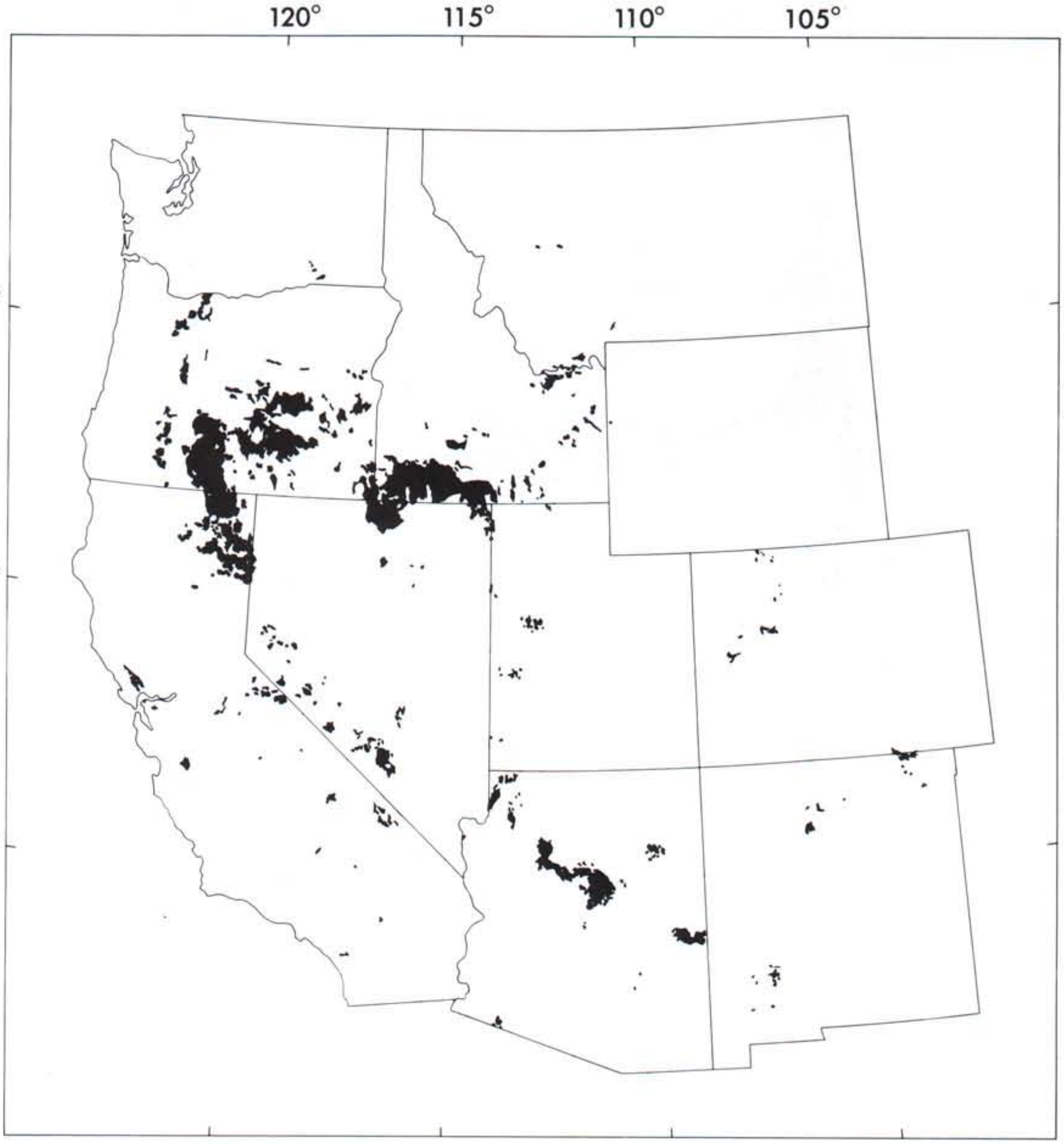

Figure 2. Map showing the distribution of upper Cenozoic volcanic rocks of all compositions extruded 5 to 10 Ma.

in the positions that they were to occupy to the present time (Smith and Luedke, 1984).

The vents for the volcanic rocks dating from 5 Ma to the present (Fig. 3) occur in many more loci that in places exhibit striking linear distribution. These linear features include coalesced loci in the Cascade Range, which extends from northern California into Canada, loci along the easterly trending Brothers fault zone of central and eastern Oregon, the arcuate-shaped Snake River Plain of southern Idaho, numerous loci in eastern California, many loci along the western margin of the Colorado Plateau in Utah and Arizona, and the northeast-trending line of loci from central-east Arizona across northern New Mexico. Rocks of basaltic composition continued to predominate during this time period, but rocks of intermediate and silicic compositions were extruded in three very significant caldera-related silicic centers: Long Valley area in California, Jemez Mountains in New Mexico, and Yellowstone Plateau in Wyoming–Montana–Idaho.

QUATERNARY VOLCANISM

Quaternary volcanism in the western conterminous U.S. was a continuation of eruptive activity within the earlier-

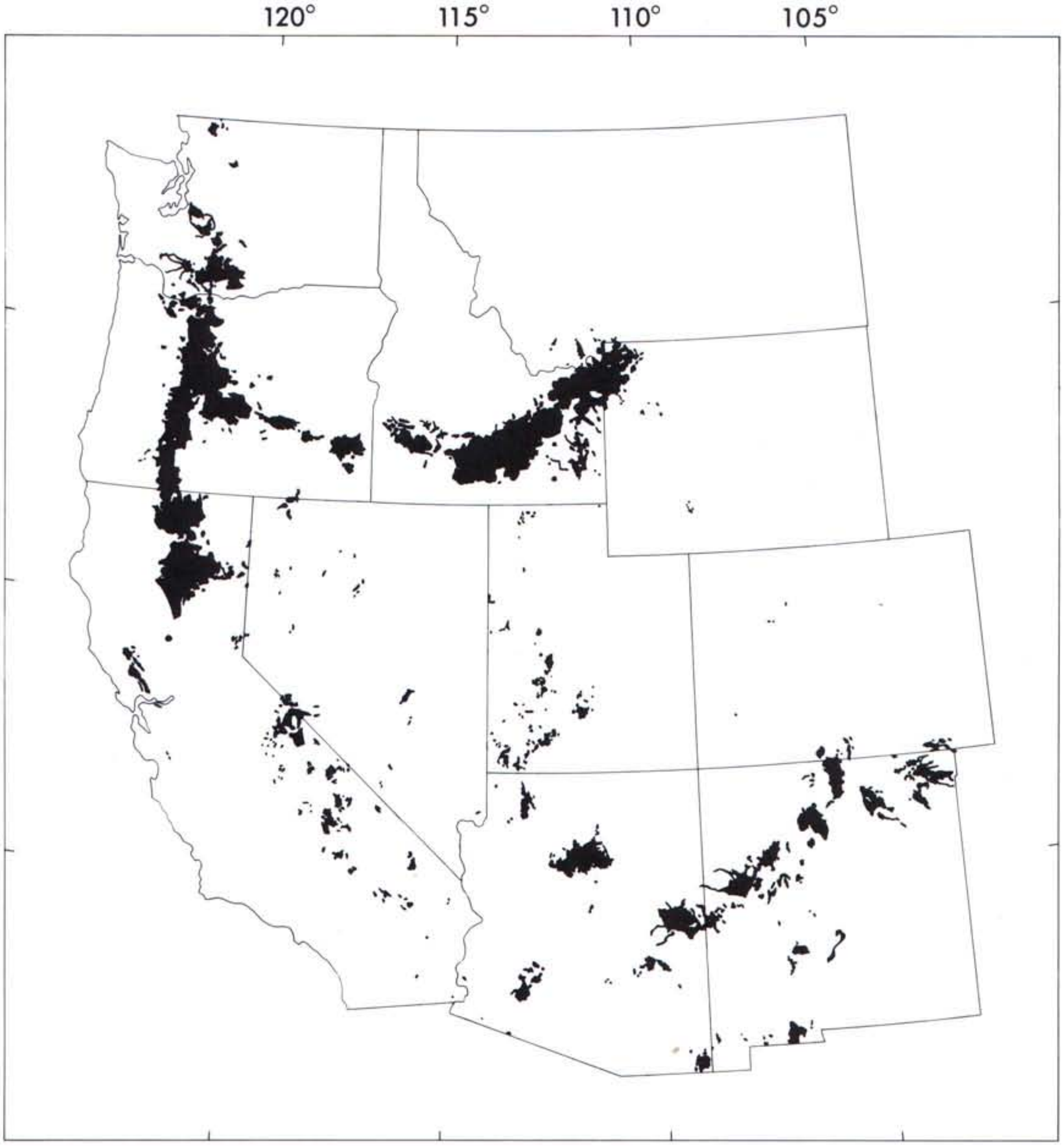

Figure 3A. Map showing the distribution of upper Cenozoic volcanic rocks of all compositions extruded 0 to 5 Ma (modified from Smith and Luedke, 1984).

established rectilinear pattern of volcanic fields (Fig. 4; Table 1). The rectilinear arrangement of loci in Figures 3B and 4 suggests probable tectonic control of volcanic loci and zones. All volcanic rock compositions ranging from mafic to silicic are recognized, with mafic compositions predominant.

REGIONAL DESCRIPTION

During and near the beginning of the Quaternary there were approximately 90 volcanic loci or centers active in the conterminous western states. For convenience of discussion, these loci have been grouped by regions, some linearly arranged.

Cascade region

Late Pliocene and Quaternary volcanism from Washington south through Oregon into northern California formed a few, widely spaced, physiographically dominant stratovolcanoes and several hundreds of intervening smaller volcanoes and lava flows along a narrow linear chain comprising the High Cascades (Mac-

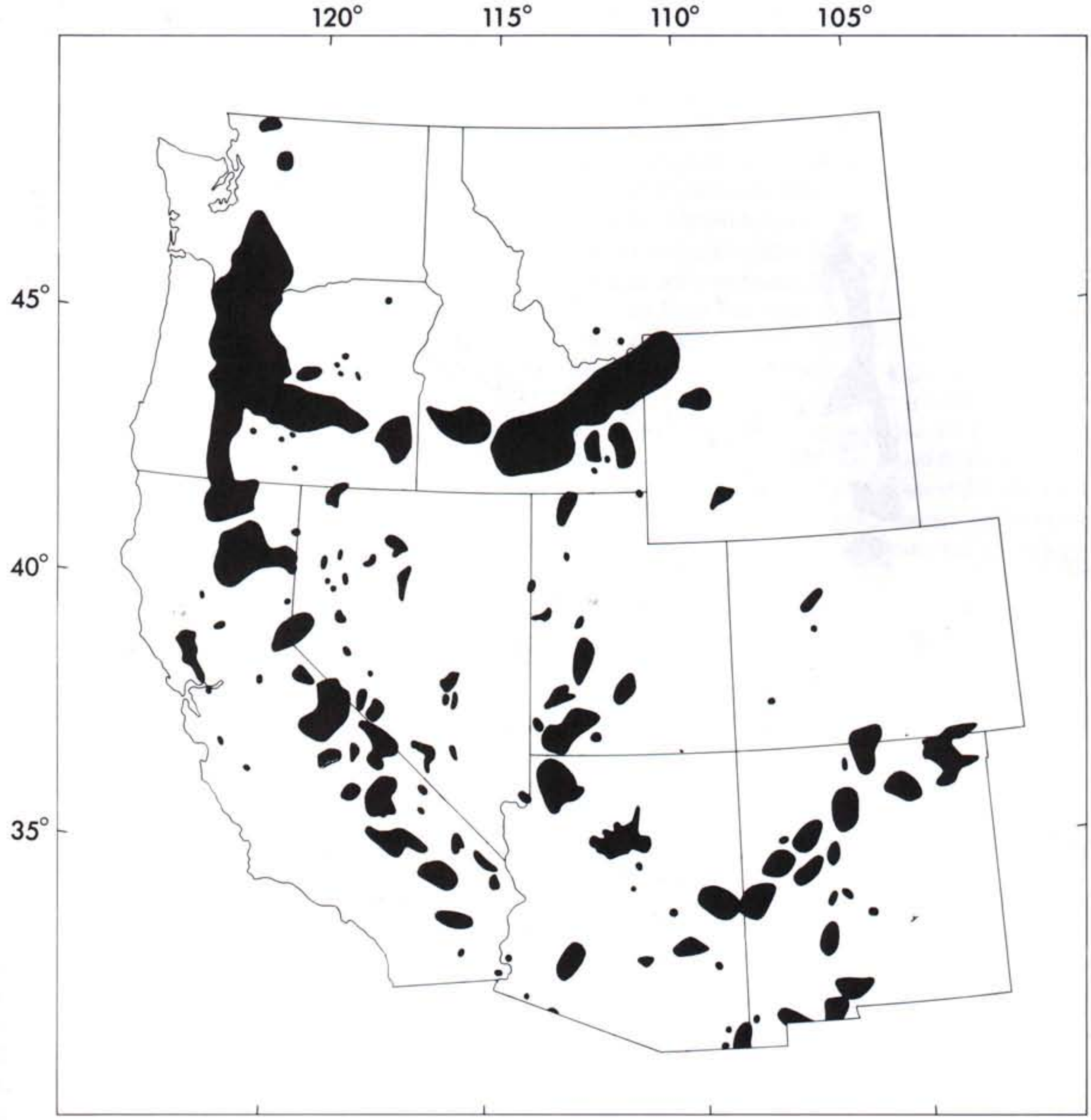

Figure 3B. Map showing the distribution of upper Cenozoic volcanic loci 0 to 5 Ma (modified from Smith and Luedke, 1984).

Leod and Swanson, 1985). Most of the eruptive activity occurred south of Mount Rainier (Fig. 5) and within about the last 2 to 3 m.y. Most eruptions probably occurred within the last few hundred thousand years. Those eruptions, principally of mafic andesite, built volcanoes upon a basement of older metamorphic, sedimentary, and igneous rocks in the north and upon a broad volcanic platform of earlier-deposited mafic lavas in the center and south. Many of the vents show north-trending alignment parallel with the range, but others are randomly dispersed or are clustered. The Cascade Range, long recognized as a region of potential volcanic activity (Crandell and others, 1979) had world attention focused upon it with the catastrophic eruption of Mount St. Helens in 1980 (Lipman and Mullineaux, 1981).

Mount Baker, the northernmost Quaternary volcano in the conterminous U.S., is a 400,000-year-old stratovolcano composed of andesitic lava flows, breccias, and pyroclastic rocks. Both it and Mount Rainier, which probably is somewhat older but similar in composition and structure, are extensively glaciated; they had minor ash eruptions in the early- to mid-19th century and intermittent fumarolic or steam activity to the present

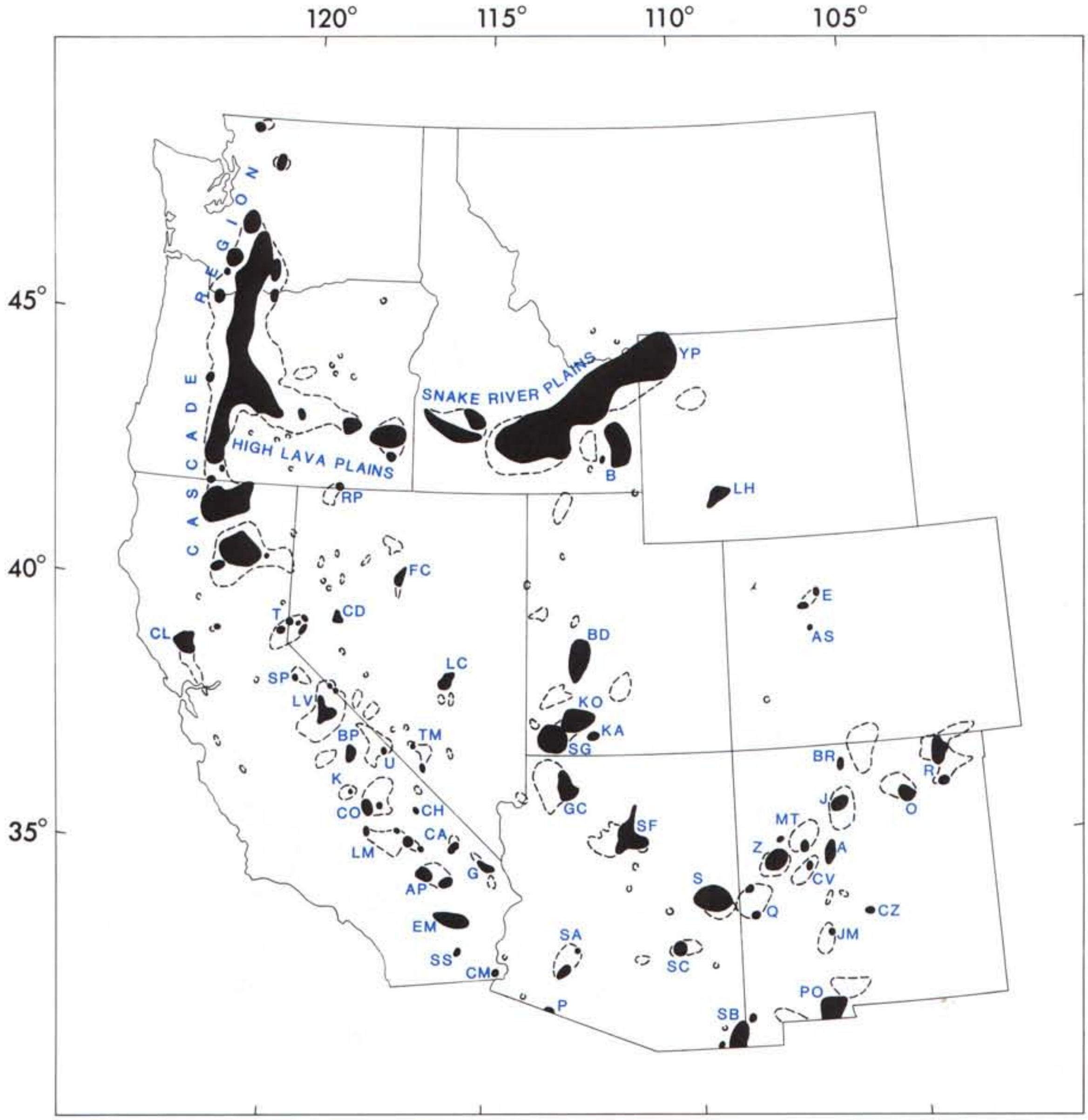

Figure 4. Map showing volcanic loci active within the last 1.6 m.y. (solid pattern) in relation to the 0 to 5 Ma volcanic loci distribution (dashed lines). Labelled Quaternary volcanic loci are listed in Table 1; see text for details.

time. The present summit cone on Mount Rainier is probably less than 2,500 years old.

Mount Adams, on the Cascade crest south of Mount Rainier, is described by Hildreth and Fierstein (1985) as an eroded andesitic compound stratovolcano less than 1 Ma in age that overlies a basement of coalescing basaltic shield volcanoes and is surmounted by a main cone of andesite and dacite with numerous generally north-south-aligned peripheral vents for mafic lavas and cinder cones. In addition, the glaciated main stratocone has had at least seven flank eruptions, one perhaps within the past 3,500 years, and continues to emit sulfurous materials at its summit fumaroles.

Glacier Peak volcano, north of Mount Rainier, erupted mostly dacitic flows and breccias, and its age, based on normal magnetic polarity of the rocks, is believed to be less than 750,000 years old. More recent eruptions from this volcano, however, produced mainly pyroclastic ejecta; a very prominent eruption that occurred about 12,000 years ago spread pumice and ash over much of the west. A minor basaltic flank eruption near the southwest base of the cone postdates glaciation (Beget, 1982).

TABLE 1. LABELED QUATERNARY VOLCANIC LOCI, BY STATE, AS SHOWN IN FIGURE 4

Arizona		**Nevada**	
GC	Grand Canyon	CD	Carson Desert
P	Pinnacate	FC	Fish Creek
S	Springerville	LC	Lunar Crater
SA	Sentinel-Arlington	RP	Railroad Point
SB	San Bernardino	TM	Timber Mountain
SC	San Carlos		
SF	San Francisco		
		New Mexico	
California		A	Albuquerque
AP	Amboy-Pisgah	BR	Brazos
BP	Big Pine	CV	Cerro Verde
CA	Cima	CZ	Carrizozo
CH	Cinder Hill	J	Jemez Mountains
CL	Clear Lake	JM	Jornado del Muerto
CM	Cargo Muchacho Mountains	MT	Mount Taylor
CO	Coso	O	Ocate
EM	Eagle Mountains	PO	Potrillo
G	Goffs	Q	Quemado
K	Kearn	R	Raton
LM	Lava Mountains	Z	Zuni-Bandera
LV	Long Valley		
SP	Sonora Pass		
SS	Salton Sea	**Utah**	
T	Truckee-Donner Pass	BD	Black Rock Desert
U	Ubehebe	KA	Kanab
		KO	Kolob
Colorado		SG	St. George
AS	Aspen		
E	Eagle		
		Wyoming	
Idaho		LH	Leucite Hills
B	Blackfoot	YP	Yellowstone Plateau

Mount St. Helens, which began to develop about 40,000 years ago, also erupted products of dominantly dacitic composition early in its eruptive history, but changed about 2,500 years ago to alternating andesitic and dacitic lava and pyroclastic flows and lahars. Its former symmetrical stratocone was decapitated and gutted by the climactic eruption of May 1980 (Foxworthy and Hill, 1982). This type of explosive eruption probably is common for the potentially active Cascade volcanoes, particularly for Mount St. Helens volcano, which has had repeated explosive eruptions during its history. As of this writing (summer 1986) eruptive activity at Mount St. Helens continues intermittently in a nonexplosive, dome-building mode.

Mount Hood, south of the Columbia River in northern Oregon, is an andesitic and dacitic stratovolcano probably less than 700,000 years old (Priest, 1982). It has erupted considerable ash and pumice during the last few centuries, most recently in the mid-1800s. Fumarolic activity is vigorous near Crater Rock dome high on its southwest flank.

The central part of the High Cascades consists of a wide, elongate, chiefly Pleistocene, volcanic platform that is composed of older high-alumina olivine tholeiitic basalt flows and younger overlapping high-alumina basaltic andesite shield volcanoes with cinder cone cores (Taylor, 1981 and 1985). Mount Washington, a deeply eroded and glaciated volcano, exposes a central plug and radial dike swarm within a large pyroclastic cone. It is typical of the slightly older, and apparently extinct, High Cascade volcanoes that include Three-Fingered Jack to the north and North Sister, Mount Thielsen, and Union Peak to the south. Also on this volcanic platform are built the younger but glaciated and eroded andesitic stratovolcano of Mount Jefferson with late satellitic cinder cones and related basalt lava flows, and a cluster of major volcanic peaks including Middle Sister, South Sister, Broken Top, Bachelor Butte, and many other smaller cones. Individually, these peaks range from older, highly eroded to younger, relatively unmarred cones and from mafic to silicic rocks in composition. The cone-shaped andesitic South Sister volcano with its summit crater is probably only a few thousand years old; it has younger rhyolitic obsidian domes and flows that issued from a south-trending fissure along its east side and a 1,900-year-old rhyodacite dome at its southwest base. North-south alignment of the numerous cones and other vents, regardless of age, is well displayed within this central part of the High Cascades.

One of the best-known Cascade volcanoes is Mount Mazama stratovolcano. A recent study (Bacon, 1983) of the eruptive history concludes that this volcano, roughly half a million years old, was constructed of andesitic and dacitic eruptive products from several major overlapping centers. A climactic eruption about 6,850 years BP formed the now lake-filled 9-km-diameter collapse caldera (Crater Lake) and deposited extensive rhyodacitic, then andesitic, ash-flow tuffs all around Mount Mazama. A post-caldera andesitic cone, called Wizard Island, rises above the lake surface near its western edge.

The little-known, partly glaciated andesitic Mount McLoughlin volcano (Harris, 1976), in the south part of the High Cascades, consists of an exceptionally large pyroclastic cone veneered by thin lava flows, and may be only about 100,000 years old. Satellitic flank eruptions have occurred within the last few thousand years.

Mount Shasta, in northern California, is one of the largest Cascade compound stratocones (Christiansen, 1985) and is about 590,000 years old. It is composed of at least four overlapping major cones composed of andesitic and dacitic lava and pyroclastic flows, lahars, and domes, and minor basaltic cones and shields. Shastina, one of the cones on the west side, is less than 10,000 years old. The most recent eruption at Mount Shasta probably occurred about 200 years ago; thermal and hot-spring activity continues near the summit.

Lassen Peak, usually considered the southernmost volcano of the Cascade Range, is a very large silicic dome field (Clynne, 1984 and 1985) that formed during the past 0.35 m.y. to perhaps as recently as about 11,000 years ago; it is mantled by avalanche-debris deposits and some pyroclastic flows. This dome field is situated on the northeast flank of the now partly destroyed and deeply eroded Pleistocene andesitic Brokeoff Volcano. Chaos Crags, a dacitic flank dome on Lassen Peak, is about 1,100 years old. Lassen volcano erupted this century from 1914 to 1921, with

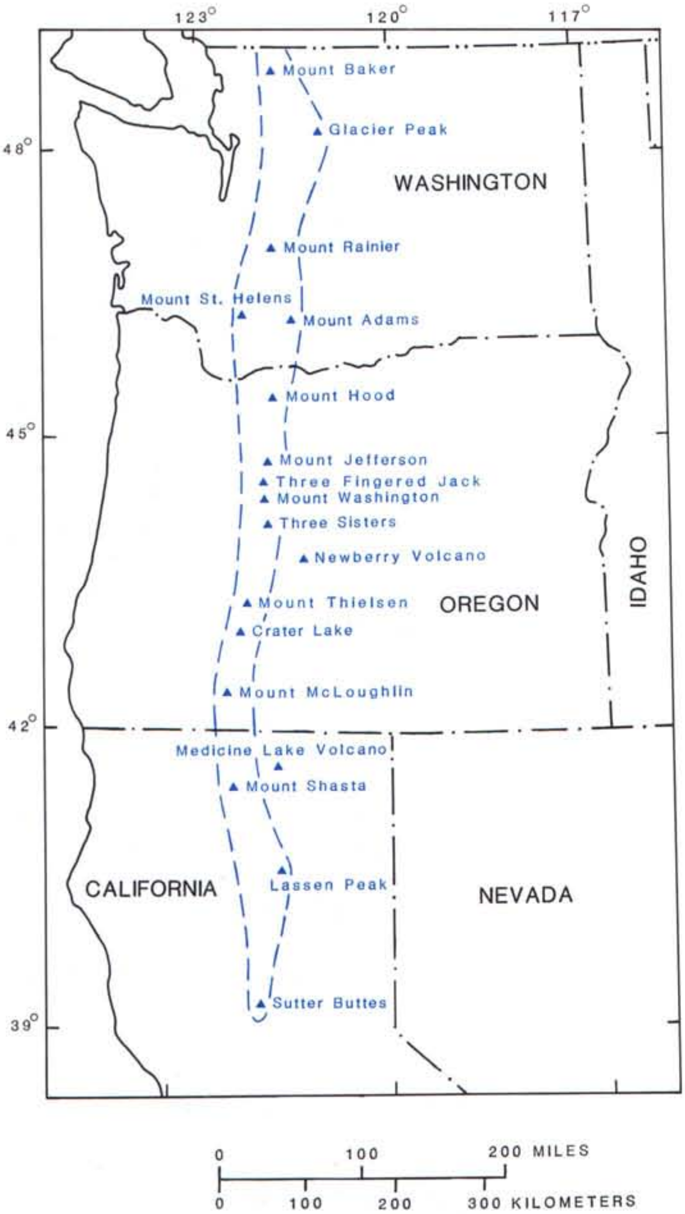

Figure 5. Sketch map showing the principal volcanoes of the Cascade Range (dashed outline) in the northwestern U.S.

several major eruptions in May 1915 that included pyroclastic flows and mudflows. The recent silicic volcanism and a well-developed hydrothermal system (Clynne, 1985) related to this volcanic center result in active thermal springs in the area.

Luedke and others (1983) consider, as the possible southern terminous of the Cascade volcanic chain, the Sutter Buttes, which is a 1 to 2 Ma cluster of several separate andesitic domes intruded by smaller dacitic and rhyolitic inner domes. This dome cluster is older than the High Cascade stratovolcanoes and is probably equivalent to some of the more deeply eroded, older, and lesser-known Cascade Range stratocones of Quaternary age.

On the eastern margin of the Cascade Range are three predominantly mafic volcanic fields that conventionally are included with the Cascades but structurally are more typical of volcanism and extensional tectonism of the Basin and Range province. The northernmost of these three fields is the Simcoe Mountains area, east of Mount Adams, in southern Washington. This field is composed mainly of basaltic shield volcanoes and cones with locally some dacitic and rhyolitic flows and domes near its eastern edge. This volcanic locus is believed to be mostly of Quaternary age, but geochronologic data are lacking. The other two fields, Newberry volcanic locus in Oregon and Medicine Lake volcanic locus in California, are discussed elsewhere in this chapter.

Remnants of a large basaltic field, in part Pleistocene in age (MacLeod, personal communication, 1986), are also found in the vicinity of Portland, Oregon, on the west side of the Cascade Range west of Mount Hood. This volcanic locus contains numerous scattered vents.

Northern California Coast Ranges

The Geysers–Clear Lake volcanic center (CL) is a very important Quaternary volcanic locus in the Coast Ranges of northern California. This locus is a large volcanic field of dominantly intermediate to silicic rocks related to eruptive activity that began in the middle to late Miocene. The focus of cones, domes, flows, and tuff rings in the northern part of this volcanic field, well documented in age and rock type (McLaughlin and Donnelly-Nolan, 1981), formed throughout the Pleistocene, with the last eruptions about 10,000 years ago. Fumarolic and hot-spring activity are still common in the area, and it is a center of active geothermal exploration and exploitation. Northward migration of volcanism to its present position at the north end of the locus, has taken place across structurally complex terrane and is affected by right-lateral offsets within the San Andreas fault system (Luedke and Smith, 1981; Smith and Luedke, 1984; Fox and others, 1985). This volcanic migration from the beginning of the Quaternary to the present was calculated by Fox and others (1985) to be about 1.35 cm/yr.

Eastern California–southwestern Arizona belt

Many Quaternary volcanic loci are scattered in a diffuse belt extending from northernmost California through eastern California to southwestern Arizona (Fig. 4). Most of these consist principally of mafic eruptive centers, but there are several notable centers that have erupted rocks of intermediate and silicic compositions.

At the northern end of this region is the Medicine Lake volcano (Fig. 5), included as part of the Cascades by some, which consists of a broad andesitic shield volcano constructed upon lower Pleistocene tholeiitic basalt lavas, as well as many basaltic and andesitic satellite cinder cones and related lava flows (Donnelly-Nolan, 1985). Both in the summit caldera and on the flanks of the shield, localized Plinian-type pumiceous eruptions occurred about 1,100 years BP (Heiken, 1978), followed by dacitic and rhyolitic thick lava domes and flows, some of which are probably only a few hundred years old. To the south and almost continuous with flows from this locus is an extensive basalt field east of and adjacent to the Lassen Peak locus in the Cascade region. Volcanism began there in late Miocene time and continued through the Pliocene to historic time, with probably a number of cones and related lava flows formed within the last few thousands or hundreds of years; Cinder Cone (east of Lassen Peak) erupted in A.D. 1851. Northerly to northwesterly trending vent alignments and generally westward volcanic migration through the late Cenozoic of predominantly basaltic lavas in this part of northern California reflect close association with Basin and Range volcanism and tectonism.

Quaternary basaltic to andesitic eruptive activity at 1 to 2 Ma produced a few local plugs, cones, and flows along the crest of the Sierra Nevada in the Truckee–Donner Pass area (T) north of Lake Tahoe in California and in the Carson and Virginia Ranges northeast of Lake Tahoe in adjacent Nevada. In addition, pumiceous rhyolite erupted within this locus to form several small local domes in the Steamboat Hills and off both flanks of the Virginia Range north and northeast of Carson City. Siliceous sinter deposits from fossil and active hot springs are present in the Steamboat Hills area.

Farther south along the crest of the Sierra Nevada is another very small yet significant volcanic locus (SP) consisting of an interglacial (pre-Tahoe) basaltic lava flow. Located in the Stanislaus River drainage a few miles west of Sonora Pass, this 150,000-year-old flow is a key marker in dating glacial events in the region (Dalrymple, 1964).

The Long Valley–Mono/Inyo Craters area (LV) is one of several major silicic centers in the eastern California region (Bailey and others, 1976) and is of interest for both geothermal and future volcanic potential. Increased seismic activity in the area, beginning in October 1978 but greatly diminished since 1983, raised scientific and public concern over the volcanic hazards and long-range effects of possible renewed eruptive activity (Miller and others, 1982). Volcanic activity began in this area about 3.2 Ma (Mankinen and others, 1986), with the major volcanism occurring within the last 1 m.y.; e.g., much of the volcanic complex of Glass Mountain at the northeast edge of Long Valley from 1.1 to 0.8 Ma (Metz and Mahood, 1985) and the very extensive ash-flow tuff related to the approximately 730,000-year-old Long Valley caldera-forming eruption (Bailey, personal communication, 1987). The volcanic rocks range in composition from basalt to rhyolite and form domes, cones, and flows. Although most of the eruptive activity in the area occurred before 50,000 years ago (Mankinen and others, 1986), both the silicic Mono Craters (Sieh, 1984) and Inyo Craters (Bailey and others, 1983; Fink, 1985) north of Long Valley were extruded within the last 40,000 years, chiefly about 10,000 years ago, and phreatic explosions at the Inyo Craters near the west side of the Long Valley caldera occurred about 650 to 550 years ago (Miller, 1985). The dacitic cones in Mono Lake are estimated to have erupted within the last 1,000 years. Hot springs and fumaroles are found in the south-central part of Long Valley. Volcanism in the Long Valley area is undoubtedly related to and controlled by the prominent northwest-trending fault system that bounds the east side of the Sierra Nevada. Hill and others (1985) describe this area as illustrating westward encroachment of Basin and Range extensional tectonics into the Sierra Nevada.

The Big Pine center (BP), the next locus south along and east of the Sierra Nevada fault-boundary front, is less than 1 m.y. old and consists of a silicic lava dome within a small field of basaltic cones and flows. Another rhyolitic dome, also less than 1 m.y. old, occurs within the Kern center (K)—located still farther south along the Sierra Nevada—but lies west of the fault-boundary front.

The Coso volcanic field (CO), located next south in eastern California near the boundary between the Sierra Nevada and the Basin and Range province, is a major silicic center with geothermal potential. It contains basaltic and rhyolitic rocks associated with volcanism and tectonism that began 3 to 4 m.y. ago and continued through much of the Pleistocene (Duffield and others, 1980). Earlier erupted basaltic to dacitic rocks occupy much of the northern and eastern parts of the field. The compositionally bimodal Pleistocene rocks in the central and southern parts of the field—consisting of high-silica rhyolites as domes and flows, and basalts as cones and flows—were emplaced in seven eruptive groups mostly between 1 Ma and 50 ka (Bacon and others, 1981).

The southernmost silicic center, at the southeast end of the Salton Sea (SS) in southeastern California, consists of a cluster of four small rhyolitic domes probably all less than 10,000 years old. A few mud volcanoes still persist here. This volcanic locus hosts a high-temperature geothermal system exploited for electrical energy.

The remaining volcanic loci within the eastern California–southwestern Arizona zone consist mostly of small separate mafic centers in the Mojave and Sonoran deserts respectively, and include the Ubehebe Craters (U) and Cinder Hill (CH) in the Death Valley area, cinder cones in the vicinity of Goffs (G), and lava flows in the Cargo Muchacho Mountains (CM) of southeasternmost California. Except for a few andesitic, perhaps dacitic, domes and flows in the Lava Mountains area (LM) in the northwestern part of the Mojave Desert, eastern California, these widely scattered centers are principally basaltic. However, some contain alkaline to subalkaline rocks (i.e., hawaiite, alkali olivine basalt, and basanite), for example, the Cima volcanic field (CA) and the Pisgah-Amboy volcanic field (AP) in California and the Pinnacate volcanic field (P) in southwestern Arizona (most of this field is in Mexico). Recent studies of the Cima volcanic field near Soda Lake in the eastern Mojave Desert, California (Dohrenwend and others, 1984; this volume), describe basaltic cinder cones, some polygenetic, and related flows forming three distinct age groups. Only one group, at the south end of the field, is Pleistocene (about 1.0 Ma to about 15 ka); the other two groups are late Miocene and early to middle Pliocene. Some of these loci consist of one or at the most a few vents, and others, such as the Sentinel-Arlington volcanic field (SA) in southwestern Arizona have many vents. Except for the Cima field, age assignment of all these mafic volcanic loci to the Quaternary is made on limited available age data and must be considered tentative; a few of the loci shown on Figure 4 undoubtedly are in part pre-Pleistocene.

Western interior region

For this discussion, the western interior region is the Basin and Range physiographic province, extending from central Oregon and Idaho southward between eastern California on the west and the Colorado Plateau and Rio Grande rift on the east, to the U.S.–Mexican border. The northern margin of this large western interior of the U.S. contains the major volcanic deposits within the region, notably in Oregon the High Lava Plains and in Idaho the eastern and western Snake River Plains. Quaternary eruptive deposits were otherwise sparsely distributed. By the beginning of the Quaternary the volcanic loci (Figs. 3 and 4) were concentrated mainly along the west (eastern California–southwestern Arizona belt) or east (Colorado Plateau and Rio Grande rift) margins of the Basin and Range province (Christiansen and McKee, 1978; Best and Hamblin, 1978). This region is typified tectonically by extensional block faulting and by either silicic or mafic volcanism since 16 Ma.

Walker and Nolf (1981) describe the High Lava Plains as a volcanic highland, analogous in part with the Brothers fault zone, that extends east-southeastward across Oregon from the Cascade region almost to the Idaho border. Some northerly trending Basin-Range block faults on the south appear to terminate or turn and merge into the northwest-trending en echelon normal faults of the Brothers fault zone. Throughout the late Cenozoic, many volcanic vents were concentrated and localized by faults in the High Lava Plains, with Newberry Volcano being the most geologically complex and geothermally significant.

Conventionally considered and discussed as one of the Cascade volcanoes (Fig. 5), the Newberry volcanic system probably is genetically more allied with extensional tectonism of the Basin and Range province. Newberry Volcano is a gently sloping, large, differentiated shield volcano mantled by several hundred cinder cones, fissure vents, and related basalt and basaltic andesite lava flows, some dacitic and rhyolitic domes and flows, and some localized pyroclastic flows and tuffs of diverse composition (MacLeod and others, 1981). The summit caldera, about 7 to 8 km in diameter, contains rhyolitic domes and flows. Volcanism in the Newberry area has been active for more than 500,000 years; the youngest eruption occurred about 1,350 years ago (MacLeod and Sherrod, 1985).

Rhyolitic rocks of the High Lava Plains younger than 10 Ma document a northwestward progression of decreasing age of silicic volcanism from east-central Oregon to near Newberry Volcano (MacLeod and others, 1976); however, mafic volcanism in the High Lava Plains shows little, if any, migration pattern from the limited studies made to date.

By Quaternary time, mafic volcanism became more focused along the High Lava Plains, in contrast to its much broader extent during the Pliocene. Many of the vents in the basaltic centers are closely related to, and localized by, the faults. These loci, several with eruptions probably less than 10,000 years old, extend southeastward from the Newberry Volcano area to include the maars, cinder cones, and lava flows in and adjacent to Fort Rock and Christmas Lake valleys, an area west of Harney Basin, the Diamond Craters area southeast of Harney Basin, and the extensive Jordan Craters area near the Oregon-Idaho state line.

Eastward in Idaho along the trend of the High Lava Plains but offset several tens of kilometers to the north, is the northwest-trending western part of the arcuate-shaped Snake River Plain (Malde, this volume). The elongated southern locus, one of two which constitute the volcanic complex in the western Snake River Plain, west-central Idaho (Fig. 4), is an old structural basin filled with a thick sequence of mainly sedimentary deposits capped by tholeiitic basalt flows and shield volcanoes mostly of late Pliocene and early Pleistocene age (Amini and others, 1984). The other smaller locus (Fig. 4) in the western Snake River Plain, west-central Idaho, consists mostly of canyon-filling basaltic lavas in the Boise River and its South Fork tributary, that were erupted from cinder and agglutinate cones within the last 2 m.y. (Howard and others, 1982). Possibly, this locus may be a western segment of a locus of vents in the east-west Camas Prairie area in the northwesternmost part of the eastern Snake River Plain.

The eastern Snake River Plain extends northeastward from south-central to east-central Idaho where it merges with the Yellowstone Plateau volcanic field in northwestern Wyoming. This basaltic plain of low relief comprises broad coalescing shield volcanoes, lava flows, and local cinder/spatter cones that overlie silicic ash-flow tuffs and associated calderas (Morgan and others, 1984). Many of the volcanic vents are aligned along small rift zones (Kuntz and others, 1982 and 1986a) that trend northwesterly at right angles to the northeast-trending axis of the plain; these rifts probably are extensions of Basin-Range faults north and south of the eastern Snake River Plain. Most of the exposed basaltic rocks of tholeiitic composition were erupted in the Pleistocene and Holocene, with peak activity within the last 1 m.y. extending in the "Craters of the Moon National Monument" area to about 2,000 years ago (Kuntz and others, 1986b). The eastern Snake River Plain probably represents the greatest accumulation of Quaternary basalts within the western conterminous U.S.

Several steep-sided hills rise above the eastern Snake River Plain in its central area, such as Big Southern Butte and East Butte; each of these hills consists of an intrusive-extrusive rhyolitic dome-flow complex believed to be of early and/or middle Pleistocene age.

The Island Park area, at the northeast end of the Snake River Plain (Christiansen, 1982), is geologically transitional from the Snake River Plain and is the westernmost part of the Yellowstone Plateau volcanic field (YP) in northwestern Wyoming and adjacent parts of Montana and Idaho. The Yellowstone Plateau volcanic field is the most voluminous accumulation of young silicic volcanic rocks, not only in the U.S. but in the world, erupted mostly since 2 Ma (Christiansen, 1984); it consists of predominantly rhyolitic rocks representing three major caldera-forming eruptions of ash flows and associated intracaldera domes and lavas. The most recent eruption in the field occurred about 70,000 years ago. Minor basaltic flows have been extruded intermittently on the margins of the rhyolitic center throughout the time span. Volcanic ashes related to the three principal catastrophic eruptions (about 2.0, 1.3, and 0.6 Ma) in the Yellowstone eruptive center have been recognized hundreds of kilometers from the Yellowstone area (Izett, 1981). The vigorous geyser, fumarolic, and hot spring activity in the Yellowstone region make this one of the most extensive surface hydrothermal regions in the world.

The Yellowstone Plateau volcanic field is situated at the intersection of the eastern end of the Snake River Plain and a broad zone we called the Rocky Mountain hinge zone, the present approximate eastern limit of igneous activity in the western U.S. (Smith and Luedke, 1984, p. 52 and Fig. 4.5). North- to northwest-trending vent alignments in the Yellowstone region reflect the structural influence of this so-called hinge zone.

In southeastern Idaho during much of the Quaternary, widespread basaltic volcanism occurred in the Soda Springs and Gem Valley areas that constitute the Blackfoot locus (B). In addition, rhyolitic domes were emplaced in two separate episodes, most recently about 50,000 years ago (Fiesinger and Nash, 1980). Basaltic ash and lava erupted as recently as 30,000 years ago. The basaltic lavas in this locus were considered to be similar to the tholeiitic basalts of the Snake River Plain, but chemical and mineralogical data suggest the basalts have an affinity with alkali olivine basalts (Fiesinger and others, 1982). Vents within this Blackfoot locus are aligned north to northwest corresponding to the dominantly north-striking extensional block faults within this region.

The northeast-southwest trend of the eastern Snake River Plain extends southwest across Idaho and northern Nevada toward the Lake Tahoe region of California and coincides with the so-called Humboldt zone (Rowan and Wetlaufer, 1981; Smith and Luedke, 1984). Quaternary volcanic activity was sparse within this zone and this part of the Basin and Range province. A small locus of vents, consisting of basaltic cinder cones and flows between 1.5 and 1.0 Ma, is located in the Fish Creek Mountains (FC) of northwest Lander County, north-central Nevada. Another small Pleistocene locus of basaltic lava flows, cinder cones (Rattlesnake Hill and Upsal Hogback), and maars (Soda Lakes) occurs in the Carson Desert (CD) of west-central Nevada (Morrison, 1964; Glancy, 1986; Chapter 10, this volume). Much of this center is buried by lacustrine and eolian deposits. Volcanism here ranges from about 1 Ma to about 24,000 years BP (Morrison and Davis, 1984), and possibly as recently as 10 ka (Morrison, personal communication, 1986).

Except for the two above-mentioned loci within the Humboldt zone, there are relatively few Quaternary volcanic loci within the Great Basin part of the western interior region. Little is known about the Railroad Point locus (RP) on the Nevada-Oregon state line, which consists of basaltic lava probably erupted from a shield volcano about 1.5 Ma. Two very small local basaltic centers, also of Quaternary age, are found on the west and south edges of the much older (middle to late Miocene) Timber Mountain volcanic center in south-central Nevada.

One young locus in the Nevada Basin-Range region, with probable eruptive activity dating from early Pleistocene or earlier to less than 10,000 years ago, is the Lunar Crater volcanic field (LC) in northern Nye County, central Nevada. Maars, cinder cones, and related lava flows of basaltic and basanitic compositions are thought to be only a few hundred thousand years old, but more data are needed to confirm this age assignment. Vents within the Lunar Crater volcanic field exhibit a definite northeast alignment, and the youngest vents and flows, of basanitic composition, occur along the west side of the axis of the field.

In the southern part of the Basin and Range province in southern Arizona and New Mexico are three volcanic loci of known Quaternary age. The San Carlos volcanic center (SC) in east-central Arizona consists of maars, ring dikes, cones, and lava flows currently dated at about 1 Ma and contains rocks of basanitic to basaltic compositions. This center is within the southwestern projection of the Jemez lineament or zone from New Mexico into Arizona (Smith and Luedke, 1984, Fig. 4.2).

The San Bernardino (Geronimo) volcanic field (SB) in southeastern Arizona consists of many basaltic cones and lava flows that erupted mostly during the early and middle Pleistocene. The most recent eruption, Paramore Crater maar, occurred between 100,000 and 25,000 years ago (Morrison, 1985). The erupted rocks are alkali-olivine basalts with many ultramafic xenoliths (Menzies and others, 1985). Alignment of the vents within the center appears to be northeasterly parallel to valley-margin faults (Drewes, 1980).

West of the San Bernardino volcanic field in Sulphur Spring Valley near the city of Douglas, Coates and Cushman (1955) report basaltic lava flows of Quaternary age interbedded with alluvial valley fill; northeast in the Animas Valley of southwestern New Mexico, Drewes and Thorman (1980) describe a widespread basaltic lava flow with a K-Ar age of 0.14 Ma. These southernmost U.S. Quaternary volcanic centers were included by Smith and Luedke (1984) in a tentatively designated northeast-trending linear zone (Truth or Consequences zone) that extends from central New Mexico southwest through Arizona into northern Mexico, parallel with the Jemez zone to the north.

Colorado Plateau margin

Several important volcanic loci of Quaternary age occur on the margins of the Colorado Plateau province. Eruptive activity along the Colorado Plateau margin started in the late Miocene and/or early Pliocene and has continued intermittently through the Quaternary to as recently as A.D. 1066 with the formation of Sunset Crater, east of the San Francisco Mountains in north-central Arizona. Age progressions of vents and vent alignments onto the Colorado Plateau are shown by some loci, whereas other loci show no consistent internal or directional pattern of migrating volcanic activity. Along the southwest margin of the Plateau, northeast-migration directions are recorded for at least the last 15 m.y., including the Quaternary. Future volcanism surely will continue this pattern. A further generalization, applicable to some loci marginal to the Plateau, is that the Quaternary basaltic magma compositions reflect alkalic to subalkalic associations in addition to the tholeiitic types.

The western margin of the Colorado Plateau region in Utah and northwestern Arizona, as herein used, lies within the Sevier rift zone (Smith and Luedke, 1984). The northern part of this margin, in northwestern Utah, had localized volcanism in the Pliocene, but apparently not in the Quaternary. This observation, however, may only represent a data gap; more information on age and field/chemical relations of the rocks are needed to better understand the volcanic loci there.

The southern part of the western margin, the transition zone between the Basin and Range and Colorado Plateau provinces in southwestern Utah and northwestern Arizona, has well-documented Quaternary volcanism (Best and Brimhall, 1974; Best and Hamblin, 1978). The several volcanic loci here are predominantly basaltic and appear related to, and controlled by, the strong extensional fault system with generally northerly trend. Basalt was erupted in these loci throughout most of the Quaternary, with probable eruptions less than 1,000 years ago in both the St. George locus (Hamblin, 1963) and Ice Springs field (Lynch and Nash, 1981) within the Black Rock Desert locus. Most of the loci have had one or more eruptions within the last 10,000 years. Basaltic volcanism has migrated eastward onto the Colorado Plateau, at a rate of about 1 cm/yr (Best and Brimhall, 1974), particularly in the St. George area of southwestern Utah and the western Grand Canyon region of northwestern Arizona.

The northern locus in west-central Utah, Black Rock Desert region (BD), includes, in addition to much basalt, some rhyolite that erupted mostly during the middle Pleistocene (Nash, 1986). Rhyolite domes and flows in the Mineral Mountains, included here as a part of this center, were emplaced from about 1.0 to 0.5 Ma. In the Twin Peaks volcanic field, also within this center, the youngest basalt flows are Pleistocene, but most of the basalt, rhyodacite, and rhyolite is older (Crecraft and others, 1981). Basaltic rocks in the Black Rock Desert locus are principally tholeiitic, whereas the basalts in the southwestern Utah loci, Kolob Plateau (KO) and St. George (SG) areas, are both alkalic and tholeiitic. In the Unikaret volcanic field, part of the western Grand Canyon region (GC) in northwestern Arizona, the many basaltic cinder cones and related lava flows are compositionally more alkalic than tholeiitic; this field includes much basanite.

The San Francisco volcanic field (SF) is the major volcanic locus on the southwest margin of the Colorado Plateau (Chapter 13, this volume). It had almost continuous volcanic activity during the late Cenozoic, particularly Pliocene and Pleistocene; Quaternary eruptive activity was confined to the eastern half of the field (Fig. 4), with the most recent eruption, Sunset Crater cone and flows, in A.D. 1066–67. This center covers about 4,800 km^2 and consists predominantly of basaltic cinder cones (more than 600) and related lava flows with a few small, local dacitic and rhyolitic domes and plugs, and the andesitic to rhyolitic domes and flows that compose the main cluster of mountain peaks. Vent alignments of many cinder cones, suggestive of some possible structural control, and the known and presumed ages indicate migration of volcanism with time northeastward in the northern part and eastward in the eastern part of this volcanic field. Tanaka and others (1986)—using paleomagnetism, age determinations, petrographic associations, geomorphology, and geologic field relations—calculated rates of this northeastward (1.2 cm/yr) and eastward (2.9 cm/yr) migration of volcanism, magma production with time, and probable eruption frequencies for the entire volcanic field. They proposed that the northeastward progression of volcanic activity within the San Francisco field may have been controlled in part by major fracture zones in the lithosphere, here the northeast-trending Colorado Lineament of Warner (1978).

Volcanic fields on the southeastern margin of the Colorado Plateau are similarly controlled by a major basement lineament (Chapin and others, 1978; Smith and Luedke, 1984). The northeast-trending Jemez zone, on the southeastern margin of the Colorado Plateau, is a tectonic and volcanic lineament or zone that extends from northeastern New Mexico southwest to the Sonoran Desert region of southwestern Arizona–northern Mexico. The several volcanic centers of the Jemez zone have complex volcanic histories that began in the late Miocene or Pliocene and continued into the Holocene. Except for the Jemez Mountains locus that includes the Valles caldera and silicic volcanic rocks (Smith and Bailey, 1968), most of the younger parts of these volcanic centers are composed of basalt. Unlike the loci on the western and southwestern margins of the Colorado Plateau, there appears to be little or no migration here of vents toward the Plateau. Also, no over-all age progression is apparent within the loci of the Jemez zone (Laughlin and others, 1976).

The little-known Springerville volcanic field (S) north of the Miocene(?) Mount Baldy–White Mountains complex, within the Jemez zone in east-central Arizona, is a large (about 3,700 km^2) and complex volcanic field of Plio-Pleistocene ages. A few K/Ar dates in the eastern part (Aldrich and Laughlin, 1981; Aubele and others, 1986) and the western part (Condit and Shafiqullah, 1985) suggest that much of the volcanic area of alkali-olivine basaltic cones and flows evolved during the Pleistocene. There are possibly both northeast- and northwest-trending alignments among the approximately 600 vents in this center, but available data permit no further extrapolation on volcanism within this field.

East of the Springerville locus in west-central New Mexico are several small remnants of the older and larger Quemado volcanic center (Q). These remnants suggest volcanism occurred here probably through much of the Quaternary, ending with the phreatomagmatic eruption of the Zuni Salt Lake maar (tuff ring) as recently as about 23 ka.

Northeastward along the Jemez zone, the Zuni-Bandera volcanic field (Z) is one of the larger of the basaltic loci on the southeast margin of the Colorado Plateau; most of the volcanic activity occurred there during the Quaternary; the most recent eruption, the McCarty's flow, occurred about A.D. 700. The many cinder and spatter cones, maars, and collapse pits in the Zuni-Bandera locus are aligned with a northeast trend. Eruptive activity within this locus shifted northward and eastward with time (Ander and others, 1981).

Most of the Mount Taylor volcanic field (MT), the next volcanic center northeastward in the Jemez zone, was constructed in late Pliocene time, but some basaltic vents and associated lava flows capping Mesa Chivato (just east of Mount Taylor) may be early Pleistocene in age. A few basalt-capped low mesas on the south edge of this locus are composed of cinder cones and associated lava flows less than 1 m.y. old. The younger basalts are mostly tholeiitic (Lipman and Moench, 1972), whereas the earlier-erupted rocks are classified compositionally as silicic alkali basalts.

The intersection of the Jemez and Rio Grande rift zones is marked by one of the most important, major, and best-studied silicic volcanic loci in the western conterminous U.S.: the Jemez Mountains volcanic field (J). This center contains volcanic products representing almost continuous eruptive activity for more than 10 m.y. (Smith and Bailey, 1968; Smith and others, 1970; Smith, 1979), with the most recent activity less than 100,000 years old. Solfataras and hot springs persist in the area. Compositions of the volcanic rocks range from mafic to very silicic with high-silica rhyolites, associated with two major caldera-forming ash-flow eruptions, the dominant rock type produced in Pleistocene time. Structural control of Quaternary rhyolite vents was related to caldera processes, but the position of the calderas, local Quaternary basalts, and indeed all older vents in the field were controlled by a combination of the northeast-trending Jemez volcanic zone and east-west extension on the north-south-trending en echelon fractures of the Rio Grande rift (Smith and Luedke, 1984).

Rio Grande rift region

The Rio Grande rift is a major tectonic feature of the southwestern North American continent, which extends southward from central Colorado through New Mexico to northern Mexico and consists of a generally north-south system of bifurcating and en echelon faults that bound many structural basins and block-fault mountain masses. For most of its length, the rift forms a physiographic and geologic boundary between the Rocky Mountains and High Plains on the east and the Basin and Range and Colorado Plateau provinces on the west (Kelley, 1979a and 1979b; Tweto, 1979). Pliocene volcanism was reasonably extensive, although scattered, along the Rio Grande rift zone, but by Quaternary time had become much more restricted to widely separated loci, mostly within the northern two-thirds of its extent in New Mexico (Fig. 4). The northern part of the Rio Grande rift in Colorado had considerable late Cenozoic volcanic activity, but none determined to be Quaternary in age unless one extends the rift to include the loci in central to northwestern Colorado.

The Brazos locus (BR), in northern New Mexico north of the Jemez Mountains locus (Fig. 4), consists of several generally north-south aligned cones with related lava flows that reflect tectonic influence of the Rio Grande rift system and suggest migration of volcanism westward toward the Colorado Plateau. The basalts of Brazos locus are alkalic or have alkalic affinities (Lipman, 1969; Lipman and Mehnert, 1975).

South of the Jemez Mountains locus, at the intersection of the Jemez and Rio Grande rift zones, Baldridge (1979) described several Quaternary mafic centers in the central Rio Grande rift region as containing both tholeiitic and alkalic basalts. The Albuquerque volcanic field, in the north part of the Albuquerque locus (A), consists of several vents and related flows, aligned approximately north–south along en echelon fractures of the same trend. Ash and lava of tholeiitic basalt erupted in this small volcanic field about 190,000 years ago. The south part of the Albuquerque locus is occuped by the Cat Hills and El Cerro del Los Lunas volcanic fields. The Cat Hills field is comparable in size to the Albuquerque field and, similarly, consists of basalt flows capped by cinder cones, erupted about 140,000 years ago. The cinder cones here are aligned along north-south-trending fractures. Basaltic volcanic rocks in the Los Lunas area, nearer the river southeast of the Cat Hills field, erupted about 1 Ma.

Cerro Verde (CV), southwest of the Albuquerque locus, is a basaltic shield or cone and associated lava flows that erupted about 300,000 years ago. This vent is included with volcanic centers of the Rio Grande rift, although it is located on the upland mesas west of the rift boundary (Woodward and others, 1975); it is close enough to perhaps be localized by buried fractures related to the Rio Grande rift system. Several other small, possibly Quaternary, basaltic cones and flows occur locally in this area.

Farther south in the Rio Grande valley but east of the river and blanketing a large area of the Jornada del Muerto (JM) in southern Socorro County, central New Mexico, is apparently a single vent with associated flows that erupted less than 1 m.y. ago. This locus represents the southern termination of loci having considerable intermittent Quaternary volcanism in the central part of the Rio Grande rift region.

About 80 km east-northeast of Jornada del Muerto is the Carrizozo volcanic center (CZ) consisting of several basaltic cinder cones and related lava flows. Lava erupted from one of these vents about 1,000 years ago and flowed southwest for a distance of more than 60 km. The Carrizozo locus appears to be localized on or near rift-related fractures on the rift's eastern edge (Woodward and others, 1975).

The southernmost Quaternary volcanic locus (PO) of significance in the south-central Rio Grande rift zone of New Mexico includes the Potrillo volcanic field and the nearby smaller Santo

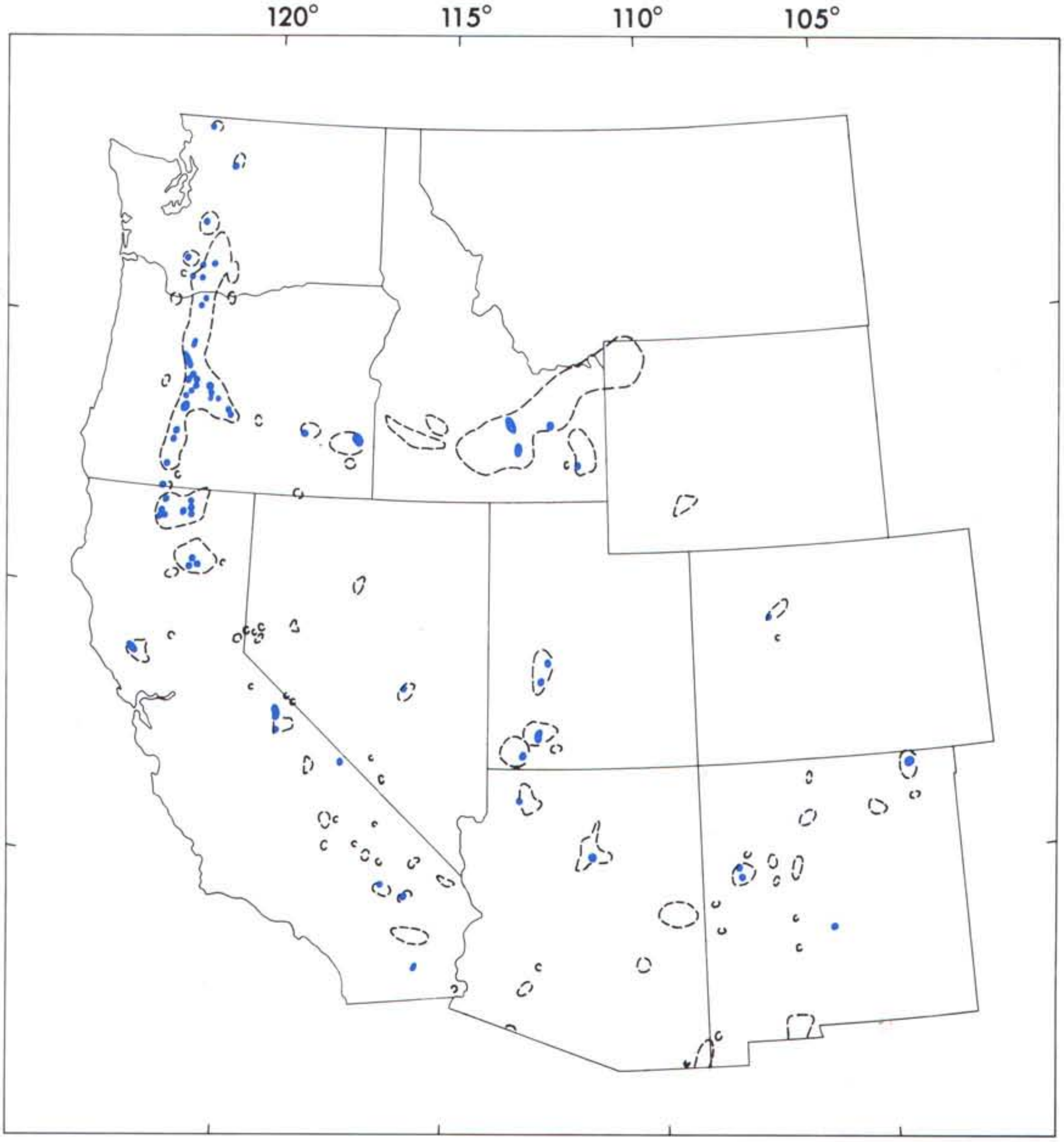

Figure 6. Map showing volcanic loci active within the last 10,000 years (blue) in relation to the 0 to 1.6 Ma volcanic loci distribution (dashed lines).

Tomas–Black Mountain center (Hoffer, 1981). Both centers erupted low-silica alkalic basalts and/or basanites. In the Potrillo center, the many cinder and spatter cones and maars (particularly the well-studied Kilbourne Hole, Hunts Hole, and Potrillo maar), though locally clustered, have an overall north–south alignment indicating probable tectonic influence of the Rio Grande rift. Volcanic activity in this center began in the early Pleistocene and continued intermittently until almost 10 ka. Vents in the Santo Tomas–Black Mountain center are aligned north-south with the rift structures; there, the erupted ash and lavas are mostly younger than 0.5 Ma.

Other regions

East of the Rio Grande rift zone in northeastern New Mexico are two volcanic loci, the Ocate and Raton volcanic fields, that compose the northeastern extent of the structural and volcanic Jemez lineament. The Ocate locus (O), the westerly of the two fields and located on the approximate physiographic boundary of the Rocky Mountains and High Plains provinces, erupted basalts and some rocks of intermediate compositions mostly during the Pliocene (O'Neill and Mehnert, 1980; Nielsen and Dungan, 1985; Chapter 16, this volume). However, a small volume of alkali olivine basalt, some transitional basalt intermediate between alkalic and tholeiitic types, and basaltic andesite was erupted from two vent areas within the southern part of this volcanic field about 1 Ma (Fig. 4). The few recognized vents (Luedke and Smith, 1978a) suggest a possible west-northwest-trending alignment within the volcanic field, but, as with the other volcanic centers in the Jemez lineament, no specific migration or direction of migration of volcanism within this center is indicated.

The Raton volcanic field (R), the northeasternmost volcanic locus in New Mexico, is located on the High Plains east of the Rocky Mountains and formed mostly in the late Miocene and Pliocene, but did have localized and significant eruptive activity through the Pleistocene to the most recent eruption of Capulin Mountain less than 10,000 years ago. Whereas the earlier erupted rocks were principally of feldspathoidal basalts, basanites, and alkali olivine basalts, the rocks erupted during the Quaternary (Stormer, 1972; Dungan and others, 1981) were cinder cones and related flows of transitional basalts, i.e., silicic alkali basalts similar to those in the Ocate volcanic center, minor amounts of nephelinite, and the two-pyroxene andesite of Sierra Grande shield volcano. Many of the cinder cones are aligned in a northwesterly direction but suggest no specific eruption pattern within this volcanic field.

Within the region of the Rocky Mountains (the Rocky Mountain hinge zone of Smith and Luedke, 1984), only a few volcanic loci had any eruptive activity in the Quaternary. Except for three centers previously discussed, the Ocate and Raton volcanic fields in northeastern New Mexico and the Yellowstone Plateau volcanic field in northwestern Wyoming, volcanic activity was minimal. The Quaternary volcanic loci in Colorado are in an area where essentially mafic volcanism has occurred since the late Oligocene in response to regional tectonism. Chapin and others (1978) suggested that these loci are along the so-called Kremmling lineament, which could be a segment of Colorado Lineament (Warner, 1978). The loci situated in central to northwestern Colorado (Larson and others, 1975; Morrison, written communication, 1986) consist of one, or at the most, very few vents each, i.e., cinder cones with related lava flows. These loci all erupted alkali-rich basalt, but at different times. The south locus near Aspen (AS) erupted before 1 Ma; in the Eagle locus (E), the south part near Dotsero erupted only about 4,000 years ago, making this the youngest volcanism in Colorado. The north part near Eagle erupted about 600,000 years ago.

The remaining volcanic locus in the Rocky Mountain region is the Leucite Hills volcanic field in southwestern Wyoming. This locus consists of a cluster of cinder cones and associated flows that erupted rocks of alkalic composition within a short time span and are a little older than 1 Ma.

SUMMARY

By the beginning of the Pliocene, about 5 Ma, a definite geographic pattern of volcanic loci and zones had become established within the western conterminous U.S. This pattern has remained largely fixed in place to the present time and resembles a rectilinear grid of intersecting linear volcanic zones (Smith and Luedke, 1984). Each zone probably reflects a major deep-seated structural feature but, in some cases, these structural features are of unknown age and origin; some zones reflect boundaries of modern tectonic provinces. Each volcanic zone consists of varying numbers of volcanic loci, with some loci common to more than one zone. The volcanic loci in turn may or may not show internal vent alignment suggestive of regional structure and may or may not indicate spatial and/or temporal migration of volcanism.

Approximately 90 loci have been active in Quaternary time within the western conterminous U.S. Quaternary volcanism was dominantly basaltic, except for the Cascade region, where both basalts and andesites were erupted. Silicic volcanism occurred locally and, in the Yellowstone region, on a spectacular and voluminous scale.

Figure 6 shows that the area distribution of active volcanic loci during the last 10,000 years is virtually the same as it was at the beginning of the Quaternary. We anticipate that future volcanic activity will occur within this established pattern.

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NOTES ADDED IN PROOF

Little change in volcanic activity has occurred in the western conterminous United States; some localized fumarolic and seismic activities continue particularly in the westernmost states. Mount St. Helens continues in its dome-building mode. Of note is an excellent new reference entitled "Volcanoes of North America: United States and Canada" published (1990) by Cambridge University Press. This book, compiled by Charles A. Wood and Jurgen Kienle, contains 354 pages of photographs, location maps, and descriptive and historical information for most known and documented volcanoes and volcanic fields in western Canada and United States, Alaska, and Hawaii.

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