Synextensional Pliocene–Pleistocene eruptive activity in the Camargo volcanic field, Chihuahua, México

Josef Jorge Aranda-Gómez
Centro de Geociencias, Universidad Nacional Autónoma de México, Campus Juriquilla, P.O. Box 1-742, Querétaro, Querétaro 76001, México

James F. Luhr
Department of Mineral Sciences, NHB-119, Smithsonian Institution, Washington, D.C. 20560, USA

Todd B. Housh
Department of Geological Sciences, University of Texas at Austin, Austin, Texas 78712, USA

Charles B. Connor
Department of Geology, University of South Florida, Tampa, Florida 33620, USA

Tim Becker
Berkeley Geochronology Center, Berkeley, California 94709, USA

Christopher D. Henry
Nevada Bureau of Mines and Geology, University of Nevada, Reno, Nevada 89557-0088, USA

ABSTRACT

The Camargo volcanic field is the largest mafic alkalic volcanic field in the Mexican Basin and Range province, and the relationship between volcanism and normal faulting is especially strong. The Camargo volcanic field lies in the northern part of the province, midway between the Sierra Madre Occidental and Trans-Pecos Texas. It is formed by Pliocene–Pleistocene (4.7–0.09 Ma) intraplate mafic alkalic volcanic rocks, some of which contain peridotite, pyroxenite, and granulite xenoliths. The volcanic field covers ~3000 km² and has an estimated volume of ~120 km³ erupted from ~300 recognized vents. Twenty-six new ⁴⁰Ar/³⁹Ar age determinations for the Camargo volcanic field and its environs show that volcanic activity began in the southwest part of the field and shifted toward the southeast at ~15 mm/yr. The average magmatic eruption rate during growth of the field was ~0.026 km³/k.y.

The Camargo volcanic field lies within an accommodation zone with west-dipping faults and east-tilted blocks to the north and east-dipping faults and west-tilted blocks to the south. These faults are expressed in the volcanic field by a N30°W-trending graben with scarps up to ~100 m high through its central part. Volcanism and faulting were at least in part coeval, and younger volcanic products commonly drape fault scarps that cut earlier lavas. Normal faulting is bracketed between 4.7 and 2.1 Ma and may have also migrated northeastward. Estimated vertical slip rates on four Pliocene faults range from 0.03 mm/yr, a likely long-term rate, to 1.67 mm/yr, interpreted as a short-term rate operative during periods of active faulting. Northwest-striking normal faults that cut alluvial-fan deposits and Pleistocene lavas in the northern Camargo volcanic field and geomorphic evidence for recent uplift to the south of the volcanic field suggest that the region is still extending.

Keywords: Basin and Range province, Chihuahua, México, extension faults, intraplate, Pliocene, slip rates.

INTRODUCTION

Continental rift zones are associated worldwide with alkalic volcanic rocks (Bailey, 1974). Despite this broad association between extensional faulting and volcanic activity, the detailed interplay between these two phenomena can be highly variable and equally highly debated. This dichotomy is most notable for the Basin and Range province. In the eastern Great Basin, Gans et al. (1989) noted a correlation between the peak of felsic ash-flow tuff eruptions and the abrupt onset of large-magnitude extension. According to their model, eruption of mafic magmas followed as slower, broadly distributed extension set in. In contrast, Axen et al. (1993) concluded that the onset of extension preceded volcanism in some areas, was coincident with volcanism in others, and postdated volcanism in still other parts of the eastern Great Basin. Glazner and Bartley (1994) offered an even more contrary position against a close association between extension and alkalic magmatism in their interpretation that mafic alkalic volcanic rocks with peridotite xenoliths from the Mojave Desert erupted during contractional or transpressional deformation.

The Oligocene “ignimbrite flare-up” of the Sierra Madre Occidental of Mexico, the largest continuous rhyolite province in the world (Swanson et al., 1978), coincided in time and space with brief pulses of rapid extension. This activity marked the transition from east-northeast compression, related to eastward
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In the RõÂo Chico graben (Aranda-GoÂmez et al., 1997; Henry and Aranda-GoÂmez, 2000). The trace of the San Marcos fault (solid line) was taken from McKee et al. (1984, 1990), and its inferred extension (dashed line) was taken from Padilla y Sánchez (1986). Inset shows the Ouachita orogenic belt in the Sierra Madre Occidental and Trans-Pecos Texas. The trace of the San Marcos fault, which lies within an antithetic transfer zone (Peacock and Sanderson, 1997) between two basin-and-range structures where the transfer zone coincides with the regional San Marcos fault (Fig. 1).

REGIONAL TECTONIC SETTING

The Camargo volcanic field is located in southeastern Chihuahua State, east of the Sierra Madre Occidental, at the juncture of several Proterozoic to Mesozoic basement structures that influence its location (Figs. 1 and 2). Scattered outcrops and well data in northern Chihuahua, Grenvillian basement is overlain by Paleozoic rocks. These may be part of the Ouachita belt, which can be traced on the surface in west Texas and disappears south of the México–United States border (Fig. 1, inset), under a thick cover of younger sedimentary and volcanic rocks. The edge of the “nonaccreted continental rocks” proposed by Coney and Campa (1987) and the extrapolated Ouachita thrust front lie a short distance north of the Camargo volcanic field. Thus, the southern edge of autochthonous Proterozoic North America and the late Paleozoic suture between Laurentia and Gondwana are thought to be near the Camargo volcanic field (Cameron and Jones, 1993).

The Camargo volcanic field is located near the San Marcos fault, which is a major structure that can be traced on the surface for ~300 km (Fig. 1) across the state of Coahuila. At the Chihuahua-Coahuila state line, the fault trace appears to end abruptly against the eastern branch of the Bolsón de Mapimí, a major Basin and Range structure (Fig. 2). Padilla y Sánchez (1986) and Grajales-Nishimura et al. (1992) interpreted that the San Marcos fault may be traced another 250 km northwestward through and past the Camargo volcanic field (Fig. 1). The San Marcos fault has a complex history (McKee and Jones, 1979; McKee et al., 1984, 1990), and it appears that since the Jurassic, it has been reactivated during each of the major pulses of deformation in the region.

The topography of the Camargo volcanic field region reflects both Laramide and Basin and Range deformation. Ranges adjacent to the Camargo volcanic field are occupied by folded Jurassic and Cretaceous rocks that are overlain by a variety of faulted and tilted Ter-
assic rocks. Regionally, Laramide folds near the volcanic field trend from north-northwest to west-northwest (Sociedad Geológica Mexicana, 1985; Tarango-Ontiveros, 1993). Tilted and faulted Eocene conglomerate and gravel are exposed adjacent to some of the folded limestone ranges (McKee et al., 1984, 1990; Bartolino, 1992). Subduction-related volcanic rocks (andesite-rhyolite) crop out extensively in the northeastern Camargo volcanic field (Figs. 2 and 3). These Tertiary volcanic rocks (K-Ar: 40±31 Ma; Smith, 1993; Smith et al., 1996) lie in the southernmost part of a 150-km-wide, east-northeast-trending belt of middle Cenozoic volcanic outcrops that extends from the Sierra Madre Occidental into west Texas (Fig. 1). Lavas of the Camargo volcanic field rest atop Cretaceous marine sedimentary rocks, middle Tertiary volcanic rocks, or, locally, gravel composed of fragments of limestone and volcanic rocks. An andesitic sill (Table 1; \( ^{40}\text{Ar}/^{39}\text{Ar} = 13.97 \pm 0.08 \text{ Ma} \)) that intruded gravel near Sierra Aguachile provides a minimum age for the Tertiary arc-related magmatism (Fig. 3).

The Camargo volcanic field overlaps an antithetic transfer zone between basin-and-range structures. South of the field, the Sierras San Francisco and El Diablo are bounded to the east by approximately north-striking, down-to-the-east normal faults (Fig. 3). These faults abruptly change strike to N30°W and project into the central Camargo volcanic field. North of the volcanic field and partly buried by its lavas, the Sierra Agua de Mayo is bounded by a N10°W, down-to-the-southwest, right-stepping, en echelon system of normal faults. The opposing Agua de Mayo and San Francisco–El Diablo fault systems meet beneath the central

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**Figure 2.** Regional setting of the Camargo volcanic field (CVF). Near the southern end of Sierra El Diablo are exposed Paleozoic volcanic rocks. The San Marcos fault, as documented by McKee et al. (1984, 1990), ends at the eastern branch of Bolsón de Mapimí. Playa lakes: LL—El Llano; EG—El Gigante; LA—Las Arenosas; ER—El Remolino.
Figure 3. Generalized geologic map of the Camargo volcanic field. The box in the central part of the volcanic field shows the location of Figure 4.
TABLE 1. SUMMARY OF 40Ar/39Ar AGES OBTAINED FOR ROCKS OF THE CAMARGO VOLCANIC FIELD AND ITS SURROUNDINGS, AND MINIMUM VERTICAL SLIP RATES FOR FAULTS IN THE CENTRAL GRABEN OF THE CAMARGO VOLCANIC FIELD

<table>
<thead>
<tr>
<th>Sample</th>
<th>Type</th>
<th>Latitude (N)</th>
<th>Longitude (W)</th>
<th>Age ±2r (Ma)</th>
<th>D age1 (m.y.)</th>
<th>Throw (m)</th>
<th>Slip rate (mm/yr)</th>
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<tbody>
<tr>
<td>CHI-56</td>
<td>Sill</td>
<td>27° 51.181'</td>
<td>104° 37.260'</td>
<td>0.40 to 41±</td>
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<td>CHI-103</td>
<td>Neck</td>
<td>27° 59.558'</td>
<td>104° 01.529'</td>
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<tr>
<td>CHI-111</td>
<td>Sill</td>
<td>27° 55.350'</td>
<td>104° 36.831'</td>
<td>3.97 ± 0.08</td>
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<tr>
<td>CHI-160B</td>
<td>Lava</td>
<td>27° 33.278'</td>
<td>104° 40.432'</td>
<td>4.69 ± 0.06</td>
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<td>CHI-43</td>
<td>Neck</td>
<td>27° 29.089'</td>
<td>104° 33.186'</td>
<td>4.11 ± 0.04</td>
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<td>CHI-171</td>
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<td>27° 23.189'</td>
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<td>CHI-84</td>
<td>Cone</td>
<td>27° 45.766'</td>
<td>104° 28.402'</td>
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<tr>
<td>CHI-33</td>
<td>Cone</td>
<td>27° 30.635'</td>
<td>104° 18.168'</td>
<td>2.36 ± 0.10</td>
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<td>Cone</td>
<td>27° 51.248'</td>
<td>104° 22.255'</td>
<td>1.35 ± 0.10</td>
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<tr>
<td>CHI-62</td>
<td>Cone</td>
<td>27° 53.743'</td>
<td>104° 16.006'</td>
<td>1.66 ± 0.10</td>
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<tr>
<td>CHI-57</td>
<td>Cone</td>
<td>28° 02.182'</td>
<td>104° 17.624'</td>
<td>0.09 ± 0.04</td>
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<td>Las Borregas fault at Cerro Mojoneras</td>
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<tr>
<td>CHI-92</td>
<td>Post-fault</td>
<td>27° 36.906'</td>
<td>104° 28.356'</td>
<td>3.20 ± 0.06</td>
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<tr>
<td>CHI-91A</td>
<td>Post-fault</td>
<td>27° 36.803'</td>
<td>104° 28.520'</td>
<td>2.35 ± 0.06</td>
<td>0.07 ± 0.05</td>
<td>&gt;50</td>
<td>&gt;0.71</td>
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<tr>
<td>CHI-91B</td>
<td>Post-fault</td>
<td>27° 36.803'</td>
<td>104° 28.520'</td>
<td>2.37 ± 0.04</td>
<td>0.03 ± 0.02</td>
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<td>&gt;1.67±</td>
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<td>Las Borregas fault at Cerro Lamojino</td>
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<tr>
<td>CHI-53</td>
<td>Post-fault*</td>
<td>27° 41.035'</td>
<td>104° 29.514'</td>
<td>2.45 ± 0.10</td>
<td>See text</td>
<td>&gt;40</td>
<td>See text!</td>
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<td>CHI-54</td>
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<td>27° 41.035'</td>
<td>104° 29.514'</td>
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<td>Las Hormigas fault</td>
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<td>CHI-93</td>
<td>Post-fault</td>
<td>27° 36.157'</td>
<td>104° 24.543'</td>
<td>2.25 ± 0.04</td>
<td>0</td>
<td>&gt;10</td>
<td>See text!</td>
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<td>CHI-94</td>
<td>Post-fault</td>
<td>27° 36.229'</td>
<td>104° 24.032'</td>
<td>2.37 ± 0.08</td>
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<td>Northern end of Las Borregas</td>
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<td>CHI-85</td>
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<td>27° 46.251'</td>
<td>104° 30.446'</td>
<td>2.94 ± 0.02</td>
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<td>CHI-87</td>
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<td>27° 45.756'</td>
<td>104° 30.289'</td>
<td>2.45 ± 0.04</td>
<td>0.55 ± 0.05</td>
<td>&gt;90</td>
<td>&gt;0.16</td>
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<td>CHI-99</td>
<td>Post-fault</td>
<td>27° 37.123'</td>
<td>104° 23.725'</td>
<td>2.24 ± 0.02</td>
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<tr>
<td>CHI-98A</td>
<td>Post-fault</td>
<td>27° 45.921'</td>
<td>104° 23.501'</td>
<td>2.14 ± 0.22</td>
<td>0.34 ± 0.03</td>
<td>&gt;10</td>
<td>&gt;0.03</td>
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<td>El Espiejo fault</td>
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<td>CHI-83</td>
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<td>27° 46.049'</td>
<td>104° 28.569'</td>
<td>2.19 ± 0.02</td>
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<td>CHI-82</td>
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<td>27° 45.992'</td>
<td>104° 29.099'</td>
<td>2.18 ± 0.06</td>
<td>0.09 ± 0.10</td>
<td>&gt;10</td>
<td>&gt;0.11</td>
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aSee Table DR1.
See discussion in text.
See age obtained from feldspar megacrysts.
To calculate slip rates we used the age obtained from groundmass separates.

part of the Camargo volcanic field to produce the central graben.

**GEOLOGIC OVERVIEW OF THE CAMARGO VOLCANIC FIELD**

The Camargo volcanic field is the largest and most voluminous of the xenolith-bearing basaltic volcanic fields in the southern Basin and Range province (Fig. 1), and its relationship to late Cenozoic faulting is the most evident. The volcanic field is formed by >300 recognized vents and extensive lava fields, which cover an area of ~3000 km². As discussed in this paper, a rough estimate of the average thickness of the lava plateau is ~40 m, yielding an estimated lava volume of ~120 km³. Twenty-three new 40Ar/39Ar ages of volcanic rocks of the Camargo volcanic field range from 4.73 ± 0.04 Ma (CHI-36) to 0.09 ± 0.04 Ma (CHI-57); all reported uncertainties are two standard deviations (2σ, Table 1). The best-known locality in the volcanic field is La Oliva, a cinder cone (Table 1: 40Ar/39Ar = 1.66 ± 0.10 Ma) where spinel lherzolite mantle xenoliths are abundant (Nimz et al., 1995). La Oliva also yields middle- to lower-crustal feldspathic granulites (Cameron et al., 1983, 1992; Nimz et al., 1986; Rudnick and Cameron, 1991) and two distinct types of subcrustal pyroxenites, one regarded as comagmatic with the host lavas and the other as comagmatic with the middle Tertiary basalts of the area (Nimz et al., 1993). Small (<3 cm) mantle and crustal xenoliths are also found throughout the Camargo volcanic field.

Ongoing faulting and block uplift in the volcanic field are evidenced by features commonly associated with these processes (Keller, 1986), such as offsets in alluvial fans, fanhead deposition near the apex of alluvial fans, flat-irons, and abrupt low-sinuosity mountain fronts. Active extension in southern Chihuahua is also supported by the observed seismicity, together with the length, focal depth, and rupture complexity associated with the Parral earthquake (1928, M = 6.5), which are similar to the values that characterize events of comparable magnitude elsewhere in the Basin and Range province (Doser and Rodriguez, 1992).

**DOMAINS OF THE CAMARGO VOLCANIC FIELD**

The lava plateau of the Camargo volcanic field is cut by a central graben, which divides the field into three large volcano-tectonic domains. The domains are bounded by normal faults or fault systems and characterized by different ages of volcanism and fault density (Fig. 3). We term these domains La Loba (southwestern), El Venado (central), and Maravillas (northeastern).

**La Loba Domain**

The southwestern part of the Camargo volcanic field is a relatively unfaulted lava plain with abundant remnants of deeply eroded cinder cones. Consequent streams, roughly perpendicular to the abrupt, southwestern boundary of the lava plain, incise deep canyons where thick lava-flow stacks are exposed. Vent locations in the southwestern part of the domain are marked by low rounded hills without vestiges of craters. The centers of these scoria mounds are commonly marked by small plug-like lava necks with near-vertical flow foliation and platy joints. Randomly oriented dikes radiate from these necks. Volcanic necks also occur in the eastern part of the La Loba domain, as well as some breached volcanoes characterized by broad shallow craters with gentle inner walls. The outer slopes of the cones commonly exceed 33° and may be as steep as 43°. These unusually steep slopes are products of erosion, which exposes resistant beds of volcanic agglutinate.

La Loba domain is bounded on the west and east by normal faults. It abruptly ends on the west along the Lagunetas fault (Fig. 3). The fault trace between Cañada La Lazada and Cañada Carrasco cuts and displaces the lava flows (Fig. 3). Near the northern and southern ends of the Lagunetas fault, the fault trace is covered by distal lava flows from younger La Loba volcanoes to the east. Therefore, activity along the Lagunetas fault probably ended before the onset of volcanism and faulting in the younger Venado domain to the east. The Las

Borregas and El Milagro fault systems separate the La Loba and El Venado domains. The fact that the trace of the Las Borregas system is locally covered by younger volcanoes (e.g., Cerros Lamojino and Las Mojoneras: Fig. 4; Cetenal, 1974) indicates that it acted as a magmatic conduit. The elliptical shape of Cerro Lamojino, having its long axis parallel to the fault, suggests that it was formed by a series of eruptions along the structure. Contact relationships around Cerro Mojoneras are complex and are best explained by several successive pulses of faulting and volcanism.

**El Venado Domain**

The central El Venado domain is characterized by numerous normal faults with scarps up to ~100 m high and small intervening playa lakes. Approximately one half of the vents are low hills with necks and radial dikes, and the rest are younger breached cones with distinct craters (Fig. 4). Short individual lava flows that caused partial collapse of the cones by rafting are common. These younger volcanic features are scattered over an older lava plain. Alignment of vents along faults indi-
cates that the faults acted as magma conduits; younger cinder cones cover some fault traces. The en echelon Agua de Mayo fault system—formed by El Alamito, El Parapeto, La Serrita, San Martín, and El Carreton faults (Figs. 2–3)—marks the eastern limit of the domain. Aerial-photographic analysis and field observations indicate that the north-northwest–striking, down-to-the-southwest Agua de Mayo fault system (Fig. 2) gradually transforms southward, beneath the Camargo volcanic field, into the northwest-striking, down-to-the-northeast San Francisco fault. Farther south this structure abruptly changes to a north trend and has a larger displacement than shown where it cuts the volcanic field. Thus, displacement on both the Agua de Mayo system from the north and the San Francisco fault from the south decreases as they approach the volcanic field. However, Mesozoic sedimentary rocks along the San Francisco fault and middle Tertiary volcanic rocks along the Agua de Mayo system show the greatest displacement, indicating significant pre–Camargo volcanic field motion along these structures. Active uplift of the east-central Sierra San Francisco is suggested by flatlows, low sinuosity of the mountain front, and fanhead deposition at the apex of alluvial fans. Occurrence of a small, internally drained basin and a playa lake (Laguna El Remolino: Fig. 2) immediately east of the mountain front and south of Cerros Prietos indicates southwestward tilting of the hanging-wall block.

In the central graben of the El Venado domain, the timing of movement along different faults can be bracketed by $^{40}$Ar/$^{39}$Ar dating of associated lava flows, as discussed subsequently. Relationships are clearest for faults with relatively small throws, where we could collect and date a lava flow cut by the fault and another draping the fault. Such cases are discussed for the faults El Espejo, El Milagro, and El Venado (Fig. 4). Extensive talus deposits that bury the fault traces hinder detailed interpretation of the geologic history at many localities. It can also be extremely difficult to establish whether a cinder cone was partly destroyed by a younger faulting episode or whether it erupted very close to an older fault scarp, built part of its cone above the footwall of the structure, and later was destroyed by mass-wasting and/or fluvial erosion.

Closed basins are common in the Camargo volcanic field region. Regional normal faulting associated with late Cenozoic basin-and-range extension controlled the locations of relatively large playa lakes such as El Gigante, Las Arenosas, El Llano, and El Remolino (Fig. 2). Internally drained basins are common in the El Venado domain, and the distribution of lakes and their association with fault scarps indicate that they were caused by slight tilting associated with normal faulting (Fig. 4). The largest basin in the El Venado domain is occupied by the El Milagro playa lake, which contains a well-developed fan delta near the trace of the Las Borregas and El Milagro fault systems (Fig. 4). Slight tilting, coupled with the modest observed displacement in the central graben of the Camargo volcanic field, indicates that Pliocene–Pleistocene extension in the area is low.

**Maravillas Domain**

The northeastern Camargo volcanic field domain, named Maravillas, is relatively unfaulted and covered by extensive lava flows; vents are particularly abundant west of La Olivia (Fig. 3). Morphologically, the vast majority of the Maravillas vents are breached cones characterized by distinct craters with relatively steep inner walls and outer cone slopes as steep as 22°. These features are interpreted as indicating only moderate degrees of erosion, lower than that found in the other two domains, and consistent with young $^{40}$Ar/$^{39}$Ar ages discussed in the next section. Cones with steep outer slopes (>33°) and exposed agglutinate beds are rare compared with the other domains, and necks are absent, except at the northeastern edge of the Maravillas domain; however, we determined that these necks are middle Tertiary in age (29.5 Ma). The presence of isolated outcrops of such older rocks, partially to completely surrounded by mafic lavas of the Camargo volcanic field, indicates that the Pliocene topography of the area was irregular. The northeastern and southeastern boundaries of the Maravillas domain are very irregular because relatively voluminous lava flows moved down prevolcanic stream beds and formed elongated lobes. Near the northeastern end of the domain, the Honorato fault (Fig. 3) cuts and displaces alluvial-fan deposits and Pleistocene lava flows of the Camargo volcanic field and is partly buried by younger alluvial deposits. Compared with other faults at the boundaries between the Camargo volcanic field domains, the Honorato fault has small displacement, just a few meters, but its trace is quite clear.

**AGE OF VOLCANISM AND FAULTING**

In total, 26 new $^{40}$Ar/$^{39}$Ar ages were determined at Berkeley Geochronology Center (Tables 1 and DR-1: Figs. 5–7) by using the analytical methods described by Sharp et al. (1996). Materials dated included 20 groundmass separates and 3 feldspar megacrysts from the Camargo volcanic field, plus 3 groundmass separates from mafic volcanic rocks older than the Camargo volcanic field. Our goals were to (1) establish the duration of activity for the Camargo volcanic field by dating vents with different estimated geomorphologic ages (Noyola-Medrano, 1995), (2) evaluate whether feldspar megacrysts, which may be xenocrystic (e.g., Luhr et al., 1995a), can provide reliable ages for their host lavas, (3) determine the ages of other mafic volcanic rocks near the Camargo volcanic field, and (4) set limits on the vertical slip rates for some of the faults in the central graben.

All samples gave readily interpretable results. Plateau and inverse isochron ages agree within analytical uncertainties for all but one very young sample. Sample CHI-57 gave imprecise plateau, 0.50 ± 0.30 Ma, and isochron ages, 0.09 ± 0.04 Ma, not surprising given its very young age. We choose the isochron age because the isochron data indicate only a small amount of excess argon. The quality of the isochron result suggests that this is the most accurate reflection of true geologic age.

**Northeastward Migration of Volcanism**

Sample ages for the Camargo volcanic field range between 4.73 ± 0.04 (CHI-36) and 0.09 ± 0.04 Ma (CHI-57, Table 1) and decrease from southwest to northeast (Figs. 2–4). The four oldest samples are from the southwestern part of the volcanic field, either within or adjacent to the La Loba domain. CHI-171 (3.91 ± 0.03 Ma) is from an outlier vent located ~15 km south-southwest of the southwestern corner of the contiguous Camargo volcanic field (Fig. 2). CHI-160B (4.69 ± 0.06 Ma) is a feldspar megacryst (Ca$_3$Na$_3$K$_2$) from a lava flow exposed at the base of the La Loba volcanic sequence in Cañada Carrasco (Fig. 3). CHI-36 (4.73 ± 0.04 Ma) came from a lava flow at the base of the sequence that is cut by the El Milagro fault (Figs. 3–4). Vent locations for these two samples are unknown. CHI-43 (4.11 ± 0.04 Ma) is from a volcanic neck near the southwestern part of the La Loba domain (Fig. 3).

The youngest rocks in the dated set are from the Maravillas domain, in the northeast...
Figure 5. $^{40}$Ar/$^{39}$Ar incremental heating spectra and inverse isochron data for samples unrelated to faulting. Uncertainties for all ages and ratios are ±2 standard deviations. Vertical height of each increment in spectra is 2 standard deviations. The preferred age for each sample is in boldface type. Subscript $tr$ denotes the initial or “trapped” component of the $^{40}$Ar/$^{39}$Ar ratio.
El Milagro fault

Pre-fault

CHI-36 whole rock groundmass
4.73 ± 0.04 Ma

Isochron Data
Age: 4.74 ± 0.04 Ma
\(^{40}\text{Ar}/^{36}\text{Ar}_{\text{fr}} = 291.1 ± 4.4\)
MSWD: 1.57, N = 11
Integrated Age = 4.67 ± 0.08 Ma

Post-fault

CHI-37 whole rock groundmass
3.07 ± 0.10 Ma

Isochron Data
Age: 3.05 ± 0.12 Ma
\(^{40}\text{Ar}/^{36}\text{Ar}_{\text{fr}} = 298.3 ± 15.8\)
MSWD: 0.16, N = 9
Integrated Age = 3.1 ± 0.6 Ma

El Espejo fault

Pre-fault

CHI-83 whole rock groundmass
2.19 ± 0.02 Ma

Isochron Data
Age: 2.19 ± 0.02 Ma
\(^{40}\text{Ar}/^{36}\text{Ar}_{\text{fr}} = 298.7 ± 2.0\)
MSWD: 1.45, N = 11
Integrated Age = 2.24 ± 0.08 Ma

Post-fault

CHI-82 whole rock groundmass
2.18 ± 0.06 Ma

Isochron Data
Age: 2.24 ± 0.10 Ma
\(^{40}\text{Ar}/^{36}\text{Ar}_{\text{fr}} = 298.0 ± 1.6\)
MSWD: 2.07, N = 12
Integrated Age = 2.3 ± 0.2 Ma

Las Hormigas fault

Pre-fault

CHI-93 whole rock groundmass
2.25 ± 0.04 Ma

Isochron Data
Age: 2.17 ± 0.06 Ma
\(^{40}\text{Ar}/^{36}\text{Ar}_{\text{fr}} = 298.6 ± 3.0\)
MSWD: 1.96, N = 10
Integrated Age = 2.31 ± 0.06 Ma

Post-fault

CHI-94 whole rock groundmass
2.48 ± 0.04 Ma

Isochron Data
Age: 2.37 ± 0.08 Ma
\(^{40}\text{Ar}/^{36}\text{Ar}_{\text{fr}} = 299.2 ± 2.2\)
MSWD: 1.93, N = 11
Integrated Age = 2.65 ± 0.10 Ma

El Venado fault

Pre-fault

CHI-99 whole rock groundmass
2.27 ± 0.02 Ma

Isochron Data
Age: 2.24 ± 0.02 Ma
\(^{40}\text{Ar}/^{36}\text{Ar}_{\text{fr}} = 308.3 ± 4.8\)
MSWD: 1.24, N = 12
Integrated Age = 2.32 ± 0.08 Ma

Post-fault

CHI-98A whole rock groundmass
2.43 ± 0.10 Ma

Isochron Data
Age: 2.14 ± 0.22 Ma
\(^{40}\text{Ar}/^{36}\text{Ar}_{\text{fr}} = 299.5 ± 2.4\)
MSWD: 1.92, N = 9
Integrated Age = 2.79 ± 0.14 Ma
part of the Camargo volcanic field (Fig. 3). These include a youthful-looking lava flow with vestigial pahoehoe ropes from the moderately eroded cinder cone Cerro Colorado (CHI-57, 0.09 ± 0.04 Ma), a lava flow that overlies the San Martín fault near the Cañón Obscuro Ranch (CHI-80, 1.35 ± 0.10 Ma), and a bomb from La Olivina (CHI-62, 1.66 ± 0.10 Ma).

All 15 dated groundmass samples and feldspars of intermediate age (2.94 ± 0.02 [CHI-85] to 2.14 ± 0.22 Ma [CHI-98A]) come from the central domain, El Venado, or just to its west (Figs. 3 and 4). The 2.36 ± 0.10 Ma age of Cerros Prietos (CHI-33), an isolated cinder-cone complex south of the El Venado domain, agrees with ages of rocks within the domain (Fig. 3).

The $^{40}$Ar/$^{39}$Ar ages demonstrate that volcanism migrated northeastward (Fig. 8B) at an average rate of ~15 mm/yr. This estimate uses only samples from identifiable vents (Fig. 8A), thereby excluding lava-plain samples whose source-vent locations are unknown and potentially distant from the sampling sites. Vent ages were projected onto a N60°E-trending line (Fig. 3), which is approximately perpendicular to the Pliocene–Pleistocene tectonic grain defined by the trends of synvolcanic normal fault scarps. The total distance (~60 km) between the oldest vent in the southwest part of the field and the youngest volcano was divided by the life span of the field (~4 m.y.), inferred from the $^{40}$Ar/$^{39}$Ar ages of known vents. It is not possible from the available data to establish whether the shift in volcanic activity was continuous or episodic. Ages shown in Figure 8A appear to cluster in intervals older than 4, approximately 3, 2.5–2.2, 1.6–1.3, and 0.99 Ma. This clustering may reflect an episodic phenomenon or incomplete sampling. Furthermore, although the oldest volcanoes are generally in the southwest part of the field and the youngest in the northeast, as seen in Figure 4, there is significant overlap between the areas with morphologically old and intermediate-age volcanoes. Migration of alkali olivine basalt vents has also been documented in the San Francisco volcanic field of Arizona (29 ± 3 mm/yr toward 93° ± 5°; Tanaka et al., 1986) and the Springerville field of Arizona (29 ± 11 mm/yr toward 93° ± 22°; Condit et al., 1989b). These displacements have been interpreted as the result of migration of the North American plate over fixed mantle hotspots.

**Eruption Rate**

A conservative estimate of the total lava volume of the Camargo volcanic field is ~120 km$^3$, based on an area of ~3000 km$^2$ and a roughly estimated average thickness of 40 m for the contiguous field. Polymictic gravels are exposed beneath lava flows in several places around the border of the volcanic plateau and along the Las Borregas and El Carretón fault scarps (Fig. 4). Our local estimates of the thickness of the volcanic pile above the gravels vary between 10 and 50 m. At the western edge of the Camargo volcanic field, in the barrancas (gullies) that drain into the El Llano playa (Fig. 2), it is evident that lava stacks may locally reach 100 m in areas with relatively high vent density, such as the central part of the La Loba and Maravillas domains. Therefore, we infer that an average of 40 m for the lava plateau is conservative. Furthermore, the fact that most volcanoes in the La Loba and El Venado domains are moderately to deeply eroded, as shown by the geomorphologic analysis performed by Noyola-Medrano (1995), makes a more precise estimate very difficult.

If the ages obtained for the oldest (CHI-36, 4.73 ± 0.04 Ma) and youngest (CHI-57, 0.09 ± 0.04 Ma) samples represent the life span of the volcanic field (4.72 Ma at the 2σ level), the long-term eruption rate is ~0.026 km$^3$/ky. This is similar to eruption rates reported for other intraplate continental volcanic fields, such as the Ocate (New Mexico), Lunar Crater (Nevada), and Durango (Mexico) fields (Table 2), but considerably lower than rates calculated for the intraplate Springerville field and the subduction-related Michoacán-Guanajuato volcanic field. All these are dwarfed by eruption rates for the world’s largest intraplate, oceanic volcanoes, such as Kilauea and Mauna Loa.

**Age of Feldspar Megacrysts**

Feldspar megacrysts are common at many localities in the Camargo volcanic field, in other late Cenozoic mafic alkalic volcanic fields in the Basin and Range province, and in mafic alkalic volcanic rocks from continental rift zones worldwide (e.g., Binns, 1969; Irving, 1974; Aspen et al., 1990). These inclinations range in size from a few millimeters to several centimeters and are either xenocrystic (foreign) or cognate with the host magma. Megacrysts are commonly released from the lava or tephra deposits by differential weathering and can easily be collected as unaltered crystals on the surface of the flows. Regardless of their origin, if these feldspar megacrysts were at a temperature in excess of the Ar blocking temperature prior to eruption, or completely degassed during transport, they could be used directly to date the eruption.

Feldspar megacrysts CHI-91B (An$_{92}$Ab$_{6}$Or$_{2}$) and CHI-54 (An$_{92}$Ab$_{6}$Or$_{2}$) were collected at the same sites as volcanic rocks CHI-91A and CHI-53, respectively, whose groundmasses were also dated. In both cases the megacryst and groundmass ages are indistinguishable at the 2σ level (Table 1). Although some workers have reported problems in obtaining reliable $^{40}$Ar/$^{39}$Ar ages from feldspar (e.g., Foland, 1974; Harrison, 1990), our results indicate that feldspar megacrysts can yield reliable eruption ages for host volcanic rocks.

**Ages of Other Volcanic Rocks near the Camargo Volcanic Field**

The three older dated volcanic rocks near the Camargo volcanic field (Fig. 3) are all calc-alkalic and compositionally distinct from the mafic alkalic rocks of the Camargo volcanic field. Two of these are from the northwest margin of the volcanic field. CHI-56 (41–40 Ma) is a hypersthene-normative basalt from the thick, columnar-jointed Cerro Prieto sill (Smith, 1993). This age is similar to those reported by Smith et al. (1996) for the oldest middle Tertiary volcanic rocks in this region. CHI-111 (13.97 ± 0.08 Ma) is a quartz-normative trachyandesite, collected from another columnar-jointed sill (Smith, 1993) ~6 km to the north-northeast. This sill is ~20 m thick and overlies ~15 m of poorly sorted, poorly consolidated, coarse-grained, polymictic sandstones that are partly conglomeratic. These sediments appear to correlate with the gravels that elsewhere underlie the mafic alkalic rocks of the Camargo volcanic field, indicating that the gravels are older than 14 Ma. The third of the older dated rocks is from the northeast margin of the Camargo volcanic field; CHI-103 (29.50 ± 0.12 Ma) is a quartz-normative trachybasalt, collected from an apparent volcanic neck northeast of Honorato de Abajo (Fig. 3). Its age is slightly younger than ages obtained by Smith et al. (1996) for the

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Figure 6. $^{40}$Ar/$^{39}$Ar incremental heating spectra and inverse isochron data for sample pairs related to faulting. Left-column samples are determined to be prefaulting. Right-column samples are corresponding samples determined to be postfaulting. See notes for Figure 5.
Northern End of Las Borregas fault

Las Borregas fault at Cerro Lamojino

Las Borregas fault at Cerro Mojoneras

Figure 7. $^{40}$Ar/$^{39}$Ar incremental heating spectra and inverse isochron data for sample pairs related to movement on the Las Borregas fault. Left-column samples are determined to be prefaulting. Right-column samples are corresponding samples determined to be postfaulting. See notes for Figure 5.
middle Tertiary Agua de Mayo volcanic group in this region.

Timing of Faulting

Our new \(^{40}\)Ar/\(^{39}\)Ar ages also set limits on the timing of faulting in the Camargo volcanic field and provide some of the first vertical slip rates for faults in the Mexican part of the Basin and Range province. Plotting the ages of dated faults along the N60°E-trending line (Fig. 8C) suggests that the faulting, or at least the cessation of faulting, may also have migrated from southwest to northeast. The observation that the Lagunetas fault cuts some La Loba lavas but is buried by others erupted in the eastern part of the domain indicates that the fault last slipped before volcanism and faulting in the Venado domain commenced; thus the Lagunetas fault was active between 4.7 and 3.05 Ma. The easternmost structure of the La Loba domain (El Milagro) is older than four faults from the Venado domain. The latter domain appears to have formed during a relatively short (~0.8 m.y.) period of synchronous volcanism and faulting. The Honorato fault, located in the northeast part of the field, was not dated in this study, but it cuts alluvium and lavas younger than those in the Venado region and thus appears to be among the youngest faults in the Camargo volcanic field.

**CALCULATION OF SLIP RATES FOR NORMAL FAULTS IN THE CAMARGO VOLCANIC FIELD**

The \(^{40}\)Ar/\(^{39}\)Ar ages (Figs. 5–7) were used to calculate minimum vertical slip rates for several faults of the Camargo volcanic field. Following the work of McCalpin (1995), we assumed that the degraded scarp heights are equivalent to the minimum vertical component, because the top of the downthrown block is invariably buried under alluvium, lake beds, and/or talus deposits of unknown thickness. Additional uncertainties in the estimated slip rates arise from (1) errors in estimating the fault-scarp heights from topographic maps with 10 m contour intervals, (2) reported uncertainties in the isotopic ages of the two samples used to bracket the age of the fault (in order to calculate minimum slip rates we used maximum age differences at the 2σ level; Table 1), and (3) the assumption that total strain accumulated over the entire time period limited by the dated samples.

Three different types of sample pairs are
recognized (Table 1). For the first type, the
two samples have ages that are well resolvable
by 40Ar/39Ar dating; these samples are associ-
ated with the El Milagro, El Venado, and El
Espejo faults, and the northern end of the Las
Borregas fault (Table DR-1). For these faults,
minimum heights divided by the maximum age
differences yield minimum slip rates aver-
aged over those time intervals. The vertical
displacement for the Borregas fault is >90 m,
corresponding to a slip rate of >0.16 mm/yr.
The minimum throw for the El Milagro fault
is 50 m, corresponding to an estimated slip
rate of >0.03 mm/yr. In the case of the El
Venado fault, the maximum age difference be-
tween the dated samples is 0.34 m.y., and the
scarp height of >10 m yields a slip rate of
>0.03 mm/yr. For the El Espejo fault, the
maximum age difference between CHI-83 and
CHI-84 is 0.09 m.y., and the scarp of 10 m
gives a slip rate of >0.11 mm/yr.

For the second type of sample pairs, rele-
vant to two different points along the same
fault scarp (Las Borregas fault at Cerro La-
mojino and at Cerro Mojoneras, Fig. 4), the
40Ar/39Ar ages overlap at the 2σ level. Slip-
rate calculations can be still made. In the case
of the Las Borregas fault at Cerro Mojoneras,
the maximum age difference between CHI-92 and
CHI-91A at the 2σ level is [(2.30 + 0.06) ×
10^9 yr] − [(2.35 − 0.06) × 10^9 yr] = 0.07 ×
10^9 yr. Thus, dividing the minimum scarp
height (∼50 m) by this maximum age differ-
ence yields a slip rate of >0.71 mm/yr. Treat-
ing the pair CHI-92 and CHI-91B in the same
way, a slip rate of >1.67 mm/yr is obtained.

The third type is represented by only one
pair of samples collected on the Las Hornigas
fault (Figs. 4–5; location in Fig. 3), where the
median value of the closely similar ages is
nonetheless the reverse of what was expected
from field relationships (Fig. 8C), and the
maximum age difference at the 2σ level is
zero (Table DR-1). It is clearly not possible to
estimate the slip rate from these data.

The implication of the ages for the second
and third types of sample pairs is that the two
bracketing eruptions and the intervening fault-
ing occurred in very narrow time intervals.
Therefore, these slip rates cannot be extrapo-
lated to the regional context, and certainly
they are not representative of long-term
deformation.

A plot of the age differences for the sample
pairs versus the minimum slip rates (Fig. 8D)
shows that the average slip rate decreases dra-
matically as the age difference increases.
Probably the high values of 0.71–1.67 mm/yr
obtained for the Las Borregas fault at Cerro
Mojoneras are short-term rates operative dur-
ing periods of active faulting. The larger age
differences between samples for the other
faults are somewhat arbitrary, dictated as they
are by the age of the uppermost plateau lava
at that site, which probably had no direct rela-
tionship to the age of the faulting, and by the
fact that displacement probably occurred
during rapid clusters of paleoearthquakes sep-
ated by longer aseismic intervals (Mc-
Calpin, 1995). Independence of the lava-plain
age from the age of faulting can be illustrated
if slip rates of the Las Borregas fault are com-
pared with samples CHI-53, CHI-85, and
CHI-36. Sample CHI-53 was collected at Cer-
ro Lamojino, a cinder cone that drapes the Las
Borregas fault (Fig. 4). CHI-85 and CHI-36
are both samples of the lava plain exposed in
the high scarps of the Las Borregas and El
Milagro fault systems. Bracketing the age of
the Las Borregas fault with samples CHI-53
and CHI-85 and considering a minimum
throw of 40 m yields a minimum slip rate of
~0.07 mm/yr. Calculating the time interval
from the pair CHI-53 and CHI-36 by using
the same 40 m throw yields a minimum slip
rate of only ~0.02 mm/yr, which is three
times lower.

**DISCUSSION**

Faulting, Volcanism, and Regional Stress

Basaltic magma erupted as scoria cones and
lava flows along active faults in the Camargo
volcanic field (e.g., Fig. 4) because dikes
abandon vertical ascent paths perpendicular to
the least principal stress direction (σ3) in favor
of more energy-efficient paths along preexist-
ing joints or faults (Conway et al., 1997). The
orientation of a fault relative to σ3 plays a key
role in determining whether a fault zone is
likely to dilate in response to dike injection
(Connor and Conway, 2000). Given the syn-
chronous nature of faulting and volcanism,
most of the active normal faults in the Ca-
margo volcanic field, especially in the El Ven-
ado domain, were perpendicular to σ3 and
were able to provide low-energy pathways for
ascending dikes.

Parsons and Thompson (1991) suggested
that the topography related to normal faulting
is suppressed near volcanic fields because
stress is accommodated by dilation of the
crust during dike injection rather than by fault
slip. This mechanism can explain much of the
variation in structure of volcanic fields. For
eexample, cinder-cone alignments are common
in low-volume, low-density volcanic fields
(e.g., Big Pine, California). In larger-volume
basaltic fields, like the Springerville (Condit
and Connor, 1996) and Michoacán-Guanajuato
fields (Connor, 1990), mapped faults are rare,
and cinder-cone alignments are less pervasive.
In the Big Pine case, rates of dike injection
were not sufficient to fully accommodate
crustal stress. As a result, faults continued to
slip, and dikes tended to parallel or inject into
these faults. In contrast, rates of dike injection
were sufficient to completely accommodate
regional tectonic stresses within the larger
Springerville and Michoacán-Guanajuato vol-
canic fields. This interpretation is also consis-
tent with the antithetical spatial relationship
between faults and plutons documented by

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**TABLE 2: CALCULATED ERUPTION RATES FOR THE CVF AND OTHER VOLCANIC FIELDS**

<table>
<thead>
<tr>
<th>Locality</th>
<th>Duration (Ma)</th>
<th>Area (km²)</th>
<th>Volume (km³)</th>
<th>Rate (km³/ka)</th>
<th>Rate/Area (km³/ka-km)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Camargo volcanic field</td>
<td>4.64</td>
<td>3000</td>
<td>120</td>
<td>0.026</td>
<td>8.6E-6</td>
</tr>
<tr>
<td>Servilleta basalt</td>
<td>1.0</td>
<td>200</td>
<td>0.2</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Ocate volcanic field</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Pulse 1</td>
<td>2.6</td>
<td>95</td>
<td>0.9</td>
<td>0.002</td>
<td>2.1E-5</td>
</tr>
<tr>
<td>Pulse 2</td>
<td>0.8</td>
<td>420</td>
<td>31</td>
<td>0.04</td>
<td>9.5E-5</td>
</tr>
<tr>
<td>Pulse 3</td>
<td>0.2</td>
<td>320</td>
<td>23</td>
<td>0.12</td>
<td>3.8E-4</td>
</tr>
<tr>
<td>Pulse 4</td>
<td>0.2</td>
<td>360</td>
<td>28</td>
<td>0.14</td>
<td>3.9E-4</td>
</tr>
<tr>
<td>Pulse 5</td>
<td>0.6</td>
<td>185</td>
<td>4.0</td>
<td>0.007</td>
<td>3.8E-5</td>
</tr>
<tr>
<td>Total</td>
<td>4.4</td>
<td>1380</td>
<td>89.9</td>
<td>0.02</td>
<td>1.5E-5</td>
</tr>
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<td>Springerville volcanic field</td>
<td>1.8</td>
<td>3000</td>
<td>300</td>
<td>0.17</td>
<td>5.6E-6</td>
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<td>Durango volcanic field</td>
<td>1.64</td>
<td>2200</td>
<td>33</td>
<td>0.02</td>
<td>9.1E-6</td>
</tr>
<tr>
<td>Michoacán-Guanajuato volcanic field</td>
<td>0.04</td>
<td>15,000</td>
<td>31</td>
<td>0.8</td>
<td>5.3E-5</td>
</tr>
<tr>
<td>Lunar Crater volcanic field</td>
<td>5.7</td>
<td>100</td>
<td>0.018</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Mount Etna**</td>
<td>0.000439</td>
<td>3.6</td>
<td>9.2</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Kilauea**</td>
<td>0.000185</td>
<td>3.3</td>
<td>17.8</td>
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<tr>
<td>Mauna Loa**</td>
<td>0.5</td>
<td>42,500</td>
<td>85</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

†This paper.
‡Dungan et al. (1986).
§Nielsen and Dungan (1985).
&&Condit et al. (1985).
††Smith (1989).
§§McIntosh, W.C. (written comm., 1998).
¶¶Hasenaka and Carmichael (1985).
in a circular area of 25 km². These values were used in the contouring process. The line vent densities obtained as follows: The number of vents around each volcano was counted.

Figure 9. Vent and fault distributions in the Camargo volcanic field. Contour lines are and Range.

Paterson and Schmidt (1999) and Schmidt and Paterson (2000).

Regionally, volcanism in the Camargo volcanic field may account for the decreases in displacement along the San Francisco and Agua de Mayo faults as they approach the volcanic field (Fig. 2). In both the La Loba (southwestern) domain and the Maravillas (northeastern) domain, rates of dike injection appear to have been sufficient to equalize, or nearly equalize, the magnitudes of principal horizontal stresses. Thus, vent alignments are less common in these domains, and fault slip is less dramatic or absent. In contrast, vent density is generally lower in the El Venado domain, as shown in Figure 4. Heavy black lines are normal faults cutting the lava fields.

Regional Versus Local Extension, and the Possibility of Active Faulting in Southeast Chihuahua

Our data set on late Cenozoic normal faulting is limited to the Camargo volcanic field and its immediate surroundings. Previous geologic studies of eastern Chihuahua and adjacent Coahuila have indicated that the region belongs either to the Rio Grande rift (Gries, 1979; Seager and Morgan, 1979; Smith and Jones, 1979) or to the Basin and Range province (e.g., papers on Chihuahua in Goodell and Waters, 1981; Henry and Aranda-Gómez, 1992, 2000). However, there are no detailed investigations on the general characteristics and evolution of Cenozoic extension in the region. Extension may have begun before 45 Ma in Chihuahua (e.g., Mauger, 1981; Capps, 1981), was definitely active in the Oligocene–Miocene (Bartolino, 1992) and Pliocene (this paper), and may continue to the present (e.g., Doser and Rodríguez, 1992). By comparison with other areas in northern and central México where more detailed information is available, we assume that extension in Chihuahua-Coahuila occurred in several distinct pulses separated by quasi-quiescent periods and that several pulses of deformation likely affected a given area. Thus, we infer that basin-and-range structures in the Camargo volcanic field were developed in several pulses of activity that cumulatively produced the present-day physiography.

The total vertical fault displacements in the Camargo volcanic field, inferred from the height of the degraded scarps in the central graben and the subtle tilting marked by the playa lakes, indicate low-magnitude Pliocene–Quaternary extension. The lower values of the calculated vertical slip rates (0.03 mm/yr) appear to be consistent with this scenario, because continuous extension since the early Pliocene at this rate would produce vertical displacements of the same order of magnitude as those observed in the central graben (~100 m). On the other hand, the higher slip-rate estimates (0.67–1.67 mm/yr) operating for 3–4 m.y. would have caused unrealistically high vertical displacements on these faults. Thus, we infer that the long-term vertical slip rates in the area must be near the low end of the values obtained. These data are consistent with what little is known about slip rates in the southern Basin and Range province (e.g., Collins et al., 1996). Clear evidence of a close relationship between faulting and volcanic activity, together with the well-documented northeast shift of volcanism in the Camargo volcanic field, suggests that both volcanism and faulting may have occurred in relatively short time spans of rapid and ephemeral activity. Therefore, the high slip rates obtained for some of the Camargo volcanic field faults with very tight time brackets may reflect short intervals with high rates of local down dropping, but do not indicate long-term deformation.

A belt of active faulting has been reported along the Rio Grande, from the region west of El Paso (Nakata et al., 1982) to the Big Bend area (Muehlberger et al., 1978; Henry et al., 1985; Collins et al., 1996). Seismicity in Chihuahua and surrounding regions and the occurrence of at least three large earthquakes of M > 6.3 (Doser and Rodríguez, 1992) indicate that extension is occurring in the region. Therefore, we interpret (1) the youthful geomorphologic features in Sierra San Francisco of the southern El Venado domain, and (2) faults that displace alluvial deposits and late Pleistocene volcanic rocks in the northern Maravillas domain as consistent with the interpretation that extension continues at a low rate in the region.
SUMMARY AND CONCLUSIONS

The Camargo volcanic field formed in the Pliocene–Pleistocene (4.73–0.09 Ma) through hundreds of eruptions of mafic alkalic magmas. More than xenoliths of upper-mantle peridotite and deep-crustal granulite. Compared with other volcanic fields of similar age and composition in the Mexican Basin and Range province, the Camargo volcanic field is unusually large and voluminous, covering ~3000 km² with a volume of ~120 km³. The long-term magmatic eruption rate is estimated at 0.026 km³/k.y., typical of other mafic-alkalic volcanic fields in the Basin and Range province.

The Camargo volcanic field developed where the regional San Marcos fault coincides with an antithetic transfer zone between the opposing San Francisco and Sierra Agua de Mayo fault systems. Volcanism and normal faulting at the Camargo volcanic field were at least in part contemporaneous, and normal faults commonly acted as magmatic conduits in the central graben. Eruptive activity migrated northeastward at ~15 mm/yr. A similar northeast shift may also have occurred in the locus or cessation of Camargo volcanic field faulting.

Minimum vertical slip rates were calculated for four faults in the central graben and range between 0.03 and 1.67 mm/yr. The average slip rate decreases as the age difference between the bracketing samples increases. The larger estimates may approximate slip rates during main faulting intervals, whereas the smaller values better reflect longer-term rates that include long intervals without fault movements. It is likely that the calculated slip rates underestimate the vertical component of the regional extension rate because volcanic activity tends to suppress normal faulting (Parsons and Thompson, 1991) and the transfer zones or bends in a segmented normal fault coincide with displacement minima in the system (Peacock and Sanderson, 1997).

Two different feldspar megacrysts yielded 40Ar/39Ar ages identical to groundmass fractions from the same eruptions, demonstrating that such megacrysts can be used to determine reliable eruption ages for their host magmas.

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