Geology of the coastal Chiapas (Mexico) Miocene plutons and the Tonalá shear zone: Syntectonic emplacement and rapid exhumation during sinistral transpression

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ABSTRACT

Late Miocene plutons in coastal Chiapas, Mexico, represent the roots of an extinct magmatic arc. Miocene granitoids of calc-alkaline composition and arc chemistry intruded into and were deformed within the Tonalá mylonite belt in the middle to upper crust. The mylonite belt is a crustal-scale shear zone extending along the western margin of the Chiapas Massif for ~150 km. Deformation is characterized by a dominantly subhorizontal lineation and subvertical foliation along a strikingly linear zone that trends ~310°. Mylonitic fabrics contain ambiguous but dominantly sinistral shear indicators. Intrusions are interpreted as syntectonic on the basis of similar U–Pb zircon crystallization age estimates (ca. 10 Ma) and the cooling age estimates obtained on neoformed micas in the mylonite. The plutons are elongated, their long axis is parallel to shear zone, and some plutons show markedly asymmetric outcrop patterns, with sheared tails that trail behind the intrusions and that are consistent with sinistral displacement. Parts of plutons were mylonitized by continuous deformation in the Tonalá shear zone, locally developing intricate pseudotachylyte and cataclasite veins slightly oblique to the mylonite foliation. Outside of the shear zone, plutons preserve magmatic fabrics. These observations are consistent with features common to syntectonic granites interpreted to have been emplaced along strike-slip shear zones in a transpressional setting. We interpret the Tonalá mylonites as representing a relict transform boundary that was slightly oblique to the Polochic-Motagua fault system, which accommodated over 100 km of sinistral displacement between the Chortis block (on the Caribbean plate) and Chiapas (on the North America plate) in late Miocene time.

INTRODUCTION

Products of middle to late Miocene arc volcanism are widespread in southern Mexico (Fig. 1; Morán Zenteno et al., 2000), as well as in the Central American highlands from Guatemala to Nicaragua (Burkart et al., 1987). However, volcanic rocks of this age range are conspicuously absent in southernmost Mexico, in the state of Chiapas. Igneous activity in the region between the Tehuantepec isthmus and Guatemala is instead represented by a suite of plutonic rocks exposed along the Pacific coastal plain, where it is often referred to as the extinct Miocene Chiapas arc (Damon and Montesinos, 1978). Rather than a gap in magmatism, recent uplift and deformation resulted in the exhumation of deeper crustal levels in Chiapas than in Oaxaca to the west, or Guatemala to the east. The Miocene arc in Chiapas is poorly understood, which is problematic because it may be a key to understanding the evolution of the North America–Caribbean plate boundary (Ratschbacher et al., 2009), and the causes of the Chiapanecan orogeny to the north (Meneses-Rocha, 2001). The sedimentary sequence is exposed in a fold-and-thrust belt that was formed during the Chiapanecan orogeny between ca. 12 and 10 Ma (Witt et al., 2012; Mandujano-Velazquez and Keppie, 2009; among others). Along its southern margin, the Chiapas Massif is delineated by a prominent escarpment (~1500 m) that borders a narrow, very low-relief coastal plain ~25 km wide. The sediment cover along the coastal plain is insignificant, and granitoids of the Miocene Chiapanecan arc are well exposed in riverbeds along the coastal plain, in isolated hills near the coast, and in the foothills of Sierra Soconusco along the southern escarpment (Fig. 2; Damon and Montesinos, 1978).

The Pacific coastal plain also includes exposures of a laterally continuous mylonite belt, striking parallel to the Chiapas Massif, that is exceptionally well exposed near the city of Tonalá. We present evidence here that this major shear zone, in the western Maya block, is a relict late Miocene...
zones (Tolson, 2005; Solari et al., 2007; Riller et al., 1992; Fig. 1). Margin of southern Mexico such as the Chacalapa and Tierra Colorada shear active Polochic-Motagua fault system with older faults along the continental 2010; Rogers and Mann, 2007). The Tonalá shear zone appears to link the Mexico, to central Honduras (Ratschbacher et al., 2009; Guzmán-Speziale, 2005) with the Polochic fault system. We present the first detailed studies of the shear zone, including geochronologic information documenting the timing of displacement along the shear zone, and the associated Miocene plutonic belt. The fault is here formally named the Tonalá shear zone. Generally accepted models for the evolution of the North America–Caribbean–Cocos plate circuit suggest that as the triple junction migrated to the southeast, the continental margin of Mexico was truncated, and a continental fragment (the Chortis block) moved eastward with the Caribbean plate (Karig et al., 1978; Meschede and Frisch, 1998; Schaf et al., 1995). The Chortis block, which includes parts of Guatemala, Honduras, El Salvador, and the Nicaragua Rise, shares with southern Mexico similar pre-Mesozoic and Mesozoic histories (Rogers et al., 2007; Silva-Romo, 2008). Recent contributions have discarded this model, but the alternative models proposed have not received much attention. Keppie and Morán-Zenteno (2005) proposed a Pacific origin for the Chortis block, with no interaction with southern Mexico in the Paleogene. More recently, Keppie and Keppie (2012) proposed an origin for Chortis in the Gulf of Mexico. A better understanding of the Miocene arc in Chiapas and the Tonalá shear zone is thus critical for the evaluation of competing models for the origin of the Chortis block. We suggest in this paper that the Tonalá shear zone accommodated relative transpressional plate motion between North America and the Caribbean plate in the late Miocene, which gradually was transferred to the Polochic and Motagua fault systems.

**SAMPLING AND METHODS FOR GEOCHRONOLOGY AND GEOCHEMISTRY**

In order to better establish the age of the Miocene Chiapas arc, we collected a sample of fresh, undeformed monzonitic facies from a pluton exposed northeast of Tepanatepec (sample 34-TEP; Fig. 2), and a sample from a sheared granodiorite exposed west of Pijijiapan (VF48;...
These samples were used for U-Pb zircon dating. Zircon crystals were separated after rock crushing using conventional magnetic and heavy liquid techniques at Centro de Geociencias (Universidad Nacional Autónoma de México [UNAM]). Zircon standard (R33) and unknowns were mounted in epoxy resin and polished down to expose the near-equatorial section of the grains. The mounts were cleaned in distilled water and in 1 N HCl and gold-coated for maximum surface conductivity. Cathodoluminescence (CL) images were obtained using a JEOL 5600 instrument (SEM) at Stanford University.

Sensitive high-resolution ion microprobe–reverse geometry (SHRIMP-RG) U-(Th)-Pb analyses were performed on individual zircon grains using the ion microprobe housed at Stanford University, California. The detailed procedures used in this study are similar to those reported in Williams (1998) and Nourse et al. (2005). Briefly, the primary oxygen ion beam (O²⁻), operated at ~2–4 nA, excavated an area of ~20–40 μm in diameter (adjustable depending on grain size) to a depth of ~1–2 μm; sensitivity was within the range 5–30 cps per ppm Pb. Data for each spot were collected in sets of five scans through the

Figure 2. Simplified geologic map of southern Chiapas, modified from Consejo de Recursos Minerales (2000), showing sampling for geochronology, petrography, and geochemistry along the Tonalá mylonite belt and the intrusions of the Miocene Chiapanecan arc. Sample localities (numbers) are used in the text with the prefix TON (e.g., TON29), except for stations numbered 46 or higher, for which we use the prefix VF (e.g., VF48).
In addition to U-Pb zircon dating, handpicking techniques were employed to separate mineral grains from three samples. The separated material was washed in acetone, alcohol, and deionized water in an ultrasonic cleaner to remove any contamination. The fractions were then rinsed with MilliQ water to ensure purity. The separated zircons were later prepared at the U.S. Geological Survey, Denver, for 40Ar/39Ar thermochronology and U-Pb dating. Nine samples were selected for major- and trace-element analysis; samples TON29, TON4, TON31, TON33, TON35, TON36, TON38, TON44, and TON45 are representative of the major intrusions studied. Major-element compositions were analyzed using the step-heating method.

### Table 1: U-Th-Pb Analytical Data for SHRIMP-RG Spot Analyses on Zircon Grains for Plutonic Rocks from Chiapas, México

| Spot name | Comments | Common 206Pb U (ppm) | U (ppm) | Th/U | Error 206Pb/238U* | Error 206Pb/238U† | Error 206Pb/238U* | Error 206Pb/238U† | Error 206Pb/238U* | Error 206Pb/238U† | Error 206Pb/238U* | Error 206Pb/238U† |
|-----------|----------|----------------------|---------|------|-------------------|-----------------|-------------------|-----------------|-------------------|-----------------|-------------------|-----------------|
| VF48-3    | Rim      | 0.626                | 107     | 6.24 | 685.49 ± 0.48     | 0.05117 ± 0.0186| 0.00145 ± 0.00007| 9.34 ± 0.46    |                   |
| VF48-11   | Rim      | 0.269                | 185     | 125  | 654.26 ± 0.37     | 0.04836 ± 0.0128| 0.00152 ± 0.00006| 9.62 ± 0.37    |                   |
| VF48-6    | Rim      | 1.150                | 167     | 131  | 629.99 ± 0.48     | 0.05532 ± 0.0130| 0.00157 ± 0.00006| 10.11 ± 0.39   |                   |
| VF48-5    | Rim      | 0.444                | 103     | 62   | 630.89 ± 0.46     | 0.04974 ± 0.0177| 0.00158 ± 0.00006| 10.16 ± 0.48   |                   |
| VF48-12   | Rim      | –0.491               | 69      | 31   | 636.74 ± 0.54     | 0.04236 ± 0.0226| 0.00158 ± 0.00006| 10.17 ± 0.56   |                   |
| VF48-4    | Rim      | 1.222                | 130     | 74   | 620.72 ± 0.42     | 0.05589 ± 0.148  | 0.00159 ± 0.00007| 10.25 ± 0.44   |                   |
| VF48-2    | Rim      | –0.477               | 57      | 24   | 647.00 ± 0.62     | 0.04248 ± 0.0274| 0.00162 ± 0.00006| 10.41 ± 0.66   |                   |
| VF48-10   | Rim      | 0.325                | 155     | 105  | 614.49 ± 0.38     | 0.04881 ± 0.139  | 0.00162 ± 0.00006| 10.58 ± 0.38   |                   |
| VF48-9    | Rim      | 0.367                | 187     | 106  | 606.44 ± 0.35     | 0.04931 ± 0.122  | 0.00164 ± 0.00006| 10.74 ± 0.35   |                   |
| VF48-7    | Rim      | 1.939                | 151     | 137  | 589.85 ± 0.41     | 0.06157 ± 0.137  | 0.00166 ± 0.00007| 10.71 ± 0.45   |                   |
| VF48-1    | Rim      | –1.005               | 109     | 70   | 579.51 ± 0.54     | 0.03832 ± 0.151  | 0.00167 ± 0.00007| 11.23 ± 0.62   |                   |

Note: Individual zircon ages in bold were used to calculate the weighted average 206Pb/238U age and its mean square of weighted deviates (MSWD). All errors given are at the 1 sigma level except for the weighted average 206Pb/238U age, which is reported at 2 sigma.

*Uncorrected atomic ratios.

1 Atomic ratios and ages corrected for initial Pb using the amount of 207Pb.
### TABLE 2. 40 Ar/39 Ar STEEP-HEATING DATA FOR IGNEOUS ROCKS FROM CHIAPAS, MÉXICO

| Step | Temp. (°C) | % 40 Ar of total | Radiogenic yield (%) | 39 Ar (moles × 10⁻¹²) | 40 Ar*/39 Ar Apparent (K/Ca) | Apparent (K/Cl) | Apparent age (Ma) | Error (Ma) |
|------|------------|------------------|----------------------|------------------------|----------------------------|----------------|------------------|------------|
| **TON-36 Granodiorite, Chiapas, biotite, total fusion** J = 0.004655% ± 0.50%, wt = 4.3 mg, #94KD48 | | | | | | | | |
| A | 1450 | 100.0 | 71.9 | 0.531824 | 1.141 | 26 | 426 | 9.56 ± 0.1 |
| **TON-36 Granodiorite, Chiapas, K-feldspar, J = 0.004303% ± 0.50%, wt = 3.65 mg, #164KD48** | | | | | | | | |
| A | 850 | 0.2 | 17.2 | 0.00224 | 2.093 | 6 | 81 | 16.18 ± 1.11 |
| B | 900 | 0.6 | 33.6 | 0.00540 | 1.485 | 16 | 221 | 11.49 ± 0.61 |
| C | 950 | 1.3 | 52.3 | 0.01183 | 1.243 | 27 | 366 | 9.63 ± 0.22 |
| D | 1000 | 4.0 | 69.9 | 0.03718 | 1.195 | 20 | 1000 | 9.25 ± 0.08 |
| E | 1050 | 5.7 | 73.3 | 0.05376 | 1.192 | 20 | 1667 | 9.23 ± 0.06 |
| F | 1100 | 7.2 | 67.5 | 0.06721 | 1.181 | 23 | 2083 | 9.14 ± 0.07 |
| G | 1200 | 7.6 | 78.2 | 0.07100 | 1.176 | 35 | 5000 | 9.10 ± 0.05 |
| H | 1250 | 7.2 | 89.9 | 0.06731 | 1.198 | 57 | 5882 | 9.28 ± 0.06 |
| J | 1300 | 6.5 | 73.5 | 0.05376 | 1.192 | 0.91 | 2577 | 9.41 ± 0.05 |
| K | 1350 | 5.8 | 44.2 | 0.05448 | 1.223 | 52 | 1610 | 9.47 ± 0.07 |
| L | 1450 | 19.8 | 22.1 | 0.18567 | 1.313 | 35 | 5000 | 10.15 ± 0.08 |
| M | 1550 | 29.2 | 15.8 | 0.27439 | 1.363 | 82 | 1538 | 10.55 ± 0.10 |
| N | 1650 | 1.8 | 3.7 | 0.01680 | 0.989 | 25 | 1621 | 5.38 ± 0.94 |
| O | 1650 | 0.7 | 3.9 | 0.00781 | 2.322 | 61 | 83 | 17.94 ± 1.31 |
| Total gas | | | | | | | | |
| A | 100.0 | 0.93850 | 10.04 |
| **TON-38 La Polka monzodiorite, Chiapas, hornblende, J = 0.004243% ± 0.50%, wt = 236.3 mg, #155KD48** | | | | | | | | |
| A | 900 | 0.4 | 25.8 | 0.01241 | 10.655 | 0.35 | 12 | 79.76 ± 1.15 |
| B | 1000 | 0.7 | 27.0 | 0.02209 | 1.063 | 0.14 | 32 | 12.08 ± 0.32 |
| C1 | 1000 | 14.0 | 60.8 | 0.45616 | 1.554 | 0.12 | 32 | 1.85 ± 0.03 |
| D1 | 1250 | 21.7 | 70.7 | 0.70709 | 1.617 | 0.12 | 32 | 2.33 ± 0.01 |
| E1 | 1500 | 39.4 | 84.8 | 1.28300 | 1.558 | 0.12 | 32 | 1.88 ± 0.02 |
| F1 | 1750 | 5.0 | 72.2 | 0.16422 | 1.574 | 0.12 | 32 | 2.01 ± 0.05 |
| G | 1200 | 4.6 | 72.4 | 0.14843 | 1.578 | 0.12 | 32 | 2.04 ± 0.05 |
| H | 1225 | 5.7 | 76.4 | 0.18730 | 1.593 | 0.12 | 32 | 2.15 ± 0.04 |
| I | 1250 | 3.5 | 72.8 | 0.13130 | 1.632 | 0.12 | 32 | 2.45 ± 0.07 |
| J | 1300 | 4.2 | 71.7 | 0.13797 | 1.702 | 0.12 | 32 | 2.98 ± 0.06 |
| K | 1450 | 0.8 | 58.0 | 0.02624 | 1.582 | 0.12 | 32 | 2.07 ± 0.24 |
| Total gas | | | | | | | | |
| A | 100.0 | 74.9 | 3.25800 | 1.618 | 0.12 | 32 | 2.34 |
| **TON-38 La Polka monzodiorite, Chiapas, biotite, total fusion** J = 0.004659% ± 0.50%, wt = 4.6 mg, #92KD48 | | | | | | | | |
| A | 1450 | 100.0 | 55.4 | 0.55305 | 1.073 | 0.35 | 12 | 79.76 ± 1.15 |
| **34-TEP Tepanatepec granodiorite, Chiapas, K-feldspar, J = 0.004895% ± 0.50%, wt = 19.7 mg, #90KD45** | | | | | | | | |
| A | 750 | 13.1 | 55.3 | 0.52997 | 1.198 | 20.3 | 532 | 10.55 ± 0.06 |
| B | 850 | 21.4 | 94.7 | 0.86544 | 1.122 | 26.7 | 13284 | 9.88 ± 0.03 |
| C | 950 | 19.7 | 96.4 | 0.79831 | 1.129 | 39.3 | 28211 | 9.94 ± 0.03 |
| D | 1100 | 23.3 | 83.4 | 0.94169 | 1.150 | 3.81 | 93 | 10.13 ± 0.04 |
| E | 1200 | 23.3 | 93.4 | 1.62149 | 1.179 | 34.37 | 93 | 10.39 ± 0.02 |
| I | 1240 | 3.5 | 92.0 | 0.24589 | 1.179 | 57 | 1592 | 10.37 ± 0.10 |
| Total gas | | | | | | | | |
| A | 100.0 | 86.7 | 4.04314 | 1.142 | 36.3 | 9490 | 10.05 |

| Note: Ages were calculated assuming an initial 40 Ar/36 Ar = 295.5 ± 0. All precision estimates are at the one sigma level of precision. Ages of individual steps do not include error in the irradiation parameter J. No error is calculated for the total gas age. | | | | | | | | | |

**34-TEP** Tepanatepec granodiorite, Chiapas, K-feldspar, J = 0.004895% ± 0.50%, wt = 19.7 mg, #90KD45

**Note:** Ages were calculated assuming an initial 40 Ar/36 Ar = 295.5 ± 0. All precision estimates are at the one sigma level of precision. Ages of individual steps do not include error in the irradiation parameter J. No error is calculated for the total gas age.
mass spectrometer at the Centro de Geociencias (UNAM; Table DR1\(^1\)). We followed the methods described by Mori et al. (2007). This study was further complemented by petrographic inspection of 12 samples, and structural observations along the shear zone.

**CHIAPAS COASTAL PLUTONIC BELT**

Rocks of the Miocene Chiapanecan arc are well exposed along the Chiapas coastal plain from the Tehuantepec isthmus to near the Guatemala border (Fig. 2). Several exposures of the plutons form isolated topographic features resulting in an “island” aspect on the coastal plain. The plutons of the Miocene belt comprise a complete magmatic series of quartz monzonite, tonalite, granodiorite, and gabbro. Locally, some of the plutons have well-developed magmatic foliations, but more often the plutonic rocks are strongly deformed and exhibit tectonic fabrics. The outcrop patterns of individual intrusions are collectively elongated parallel to the strike of the massif (~310°). In plan view, the plutons have aspect ratios of ~6:1 or greater. Typically, Permian granitoids are the host rock to the Miocene plutons, but a little studied and conspicuous suite of metamorphic rocks, the protolith ages of which are unknown, is also intruded by the Miocene granitoids.

Outcrop patterns in the coastal Chiapas pluton belt are conspicuous when compared with pluton exposures west of Tehuantepec, which are generally dispersed over a wider area (Fig. 1). In Chiapas, the plutons are concentrated along the Tonalá shear zone, and they are elongated parallel to the shear zone on the basis of surface exposures. The largest volume of plutons in Chiapas appears to crop out near the western end of the Tonalá shear zone near Zanatepec, where the fault curves and branches to the northwest.

The Tehuantepec area is characterized by Jurassic red beds, mid-Cretaceous platform and basinal carbonate rocks, and fine-grained siliciclastic rock of Upper Cretaceous age exhibiting low-grade metamorphism (Pérez-Gutiérrez et al., 2009). This area also contains widespread outcrops of Oligocene and Miocene intrusions, which yield dates between ca. 29 and 13 Ma (Morán-Zenteno et al., 2000), and scattered outcrops of felsic volcanic rocks of similar age in the west. In some areas of the Tehuantepec isthmus, such as near Ixtepec, Miocene conglomerate deposits hundreds of meters in thickness are preserved. These conglomerates are inferred to be also present offshore in the Tehuantepec Gulf; Sánchez-Barreda (1981) described cuttings from an offshore well as composed mainly of volcanic and plutonic clast conglomerate, which we reinterpret here.

**Petrography**

Samples of the Miocene intrusions along the Tonalá shear zone were studied petrographically (Fig. 3). Modal compositions were determined by point counting, and these indicate that the rocks examined are granodiorite, quartz monzonite, and tonalite following the Le Bas and Streckeisen (1991) classification. Mineral parageneses in all the samples examined are plagioclase > quartz > K-feldspar > biotite >> oxides. Samples TON34G (Tepanatepec body), TON38G (La Polka), and TON29H (shear zone) also contain hornblende. Accessory minerals (<<1 vol%) in all the rocks include titanite, apatite, and zircon. Primary mineralogy is well preserved in all but one sample (TON31D, Arriaga), where plagioclase is partially replaced by biotite, and the brittle fractures are filled with microcrystalline quartz. Sample TON31D also contains small clusters of opaque minerals along grain boundaries that likely reflect interaction with hydrothermal solutions. The only signs of hydrothermal (or retrograde?) alteration are small amounts of calcite and epidote in sample TON38G and incipient chloritization of biotite in other samples.

Fibers of the Miocene granitoids range from magmatic to solid state at the mesoscale. Textures indicate that most samples in the collection were affected by dynamic metamorphism. Crystal-plastic deformation textures in plagioclase (Fig. 3) indicate temperatures near 500 °C, but textures vary along the shear zone. The igneous textures observed are holocristalline, inequigranular, and fine to medium (1–5 mm) grained. Typical textures are either porphyritic or seriate, where plagioclase tends to form the largest crystals, which usually are euhedral or subhedral. Quartz and K-feldspar crystals (orthoclase or less frequently microcline) tend to be anhedral and fill irregular spaces between the plagioclase crystals. Large crystals of K-feldspar sometimes contain poikilitic inclusions of plagioclase and/or biotite. Quartz commonly displays undulatory extinction, and, in those samples that are slightly deformed, quartz forms fine-grained polycrystalline aggregates with sutured intracrystalline contacts. Biotite and hornblende vary from euhedral (biotite) to anhedral (biotite and hornblende) and tend to occur together associated with accessory minerals. In samples TON38G and TON39H (both from the La Polka pluton), the ferromagnesian minerals define a weak foliation, which appears to be unrelated to dynamic metamorphism, as they are comparatively coarse grained and independent of other signs of dynamic recrystallization. Therefore, these two rocks are classified as foliated tonalites.

**Geochronology**

The \(^{40}\)Ar/\(^{39}\)Ar cooling age estimates obtained in this study are within a narrow range between ca. 10 and 12 Ma. Table 2 provides all step-heating data and includes the identification of individual step, plateau, average, and total gas ages for each sample. An individual step age represents the apparent age obtained for a single temperature step analysis. Plateau ages are identified when three or more contiguous steps in the age spectrum agree in age, within the limits of analytical precision, and contain more than 50% of the \(^{39}\)Ar released from the sample. The average ages (shown in Fig. 4) are calculated from contiguous steps forming no plateau but containing more than 50% of the gas with the intention of obtaining the best age approximation for the sample.

TON36, a granodiorite deformed by dynamic metamorphism collected from the western Arriaga pluton, yields a biotite total fusion age of 9.56 ± 0.05 Ma. The Ar release spectrum of the K-feldspar separate is saddle shaped (Fig. 4) and does not yield a plateau age. The western Arriaga body (Fig. 2) has an exposed width of ~10 km on its eastern side and an elongated tail, ~30 km long, extending to the west-northwest parallel to the Tonalá shear zone. The pluton is delineated on its northern margin by a band of mylonitic granitoid. TON38 is from tonalitic facies of a somewhat smaller pluton of similar shape (with a long stretched tail extending to the west-northwest; Fig. 2). A hornblende separate yields a plateau age of 12.0 ± 0.05 Ma, and a total fusion biotite age of 9.0 ± 0.05 Ma (Table 2).

40-TEP was collected from an elongated granodiorite body; K-feldspar from this sample yields a plateau age of 9.92 ± 0.06 Ma. Sample 34-TEP yields a U-Pb zircon weighted mean age of 10.8 ± 0.3 Ma (Table 1; Fig. 5). Finally, sample VF48 is from a protomylonite exposed within an elongated tonalitic pluton northwest of Pijijiapan (Fig. 2). This sample yields a weighted mean U-Pb zircon age of 10.2 ± 0.3 Ma. This intrusion is ~30 km long, with an aspect ratio of ~8:1, not atypical of the Miocene pluton series. In summary, the plutons of the Miocene Chiapas arc between Tepanatepec and Pijijiapan appear to have been intruded between ca. 12.5 and 10 Ma, with rapid cooling to temperatures below 250 °C by ca. 10 Ma.
Chiapas Miocene plutons along the Tonalá shear zone | RESEARCH

Figure 3. (A–B) Undeformed granodiorite with inequigranular-seriate texture (sample TON34-G). K-feldspar was stained with Na cobaltinitrite and has a cloudy appearance in plane polarized light (ppl.). Biotite is slightly altered to chlorite. (C) Quartz commonly displays marked undulatory extinction in undeformed or mildly deformed rocks; plagioclase is slightly altered to fine-grained sericite. K-feldspar occasionally has gridiron twinning (sample TON30F). (D–E) Mildly deformed granodiorite: Some biotite crystals appear “smeared,” defining a weak foliation, quartz has experienced polygonization and grain-size reduction, and some plagioclase crystals display slightly bent twins due to internal deformation (sample TON36E, crossed nichols). Biotite located along the foliation is altered to chlorite and secondary spinel (E: ppl). (F) Igneous texture in intensely deformed bands within the protomylonites has been obliterated. A marked foliation, defined by secondary biotite and finely recrystallized quartz, wraps around rounded plagioclase crystals. Primary biotite has pressure tails formed by secondary, relatively coarse-grained biotite. The fine-grained aggregate was counted as matrix (M) during the modal analysis (sample TON21, crossed nichols). (G–H) Sample TON46E is unique in the studied set as it displays a marked foliation defined by very fine-grained secondary biotite and recrystallized quartz. Porphyroclasts are elongated parallel to the foliation and show intense internal microfracturing and undulatory extinction. The foliation is cut by brittle microfaults (arrows). Key for abbreviations: Ks—K-feldspar, Pl—plagioclase, Q—quartz, Bi—biotite, Ch—chlorite, Hb—hornblende, Sp—sphene, My—myrmekite, M—matrix. The scale bars are 200 μm.
Figure 4. Argon release spectra and inverse correlation diagrams for samples from the Tonalá mylonite belt. MSWD—mean square of weighted deviates.
Chiapas Miocene plutons along the Tonalá shear zone | RESEARCH

Figure 5. (A, D) Tera-Wasserburg diagram for U-Pb isotope ratios of zircons for samples from the Chiapas Miocene arc. Error ellipses of individual spots are 2σ. (B, E) Zircons used in mean age calculation. (C, F) Cathodoluminescence images of zircons from samples VF48 and 34-TEP, respectively. MSWD—mean square of weighted deviates.
The available geochronologic data indicate that the emplacement ages of deformed and undeformed plutons are indistinguishable.

Geochemistry

The plutonic assemblage we sampled includes quartz monzonite, granodiorite, tonalites, and diorite, all of which are slightly peraluminous. The assemblage has characteristics of typical arc melts. Multi-element diagrams (Fig. 6A) show enrichment in high-ionic-radius elements (Rb, Cs, Sr, Ba) with respect to high field strength elements. There is enrichment in light rare earth elements (La, Ce, Eu; Fig. 6B), relative to heavy rare earth elements (Gd, Tb, Lu). Also, there are positive anomalies of Ba, Pb, and Sr, and relative depletion of Nb and Ta. The latter is considered a geochemical characteristic of magmatic arcs (Hawkesworth et al., 1993). Two samples (TON45 and TON29), from the Tonala area, however, deviate from this general pattern. These samples appear to belong to a different magmatic suite. Their rare earth element (REE) patterns show Eu anomalies, and less enriched light REEs relative to heavy REEs.

TONALÁ SHEAR ZONE

We named the Tonala shear zone after exposures at the outskirts of Tonala city along the Rio Zanatepec (Fig. 2). The shear zone is characterized by protomylonitic to ultramylonitic textures in Permian intrusions of the Chiapas Massif, the Miocene plutons of the coastal series, and sedimentary carbonate and metasedimentary rocks for which protolith ages are uncertain. We estimate the mylonite belt to have a thickness of ~3–4 km, based on the distribution of nearly continuous exposures north of the La Polka pluton, and the estimate was verified by triangulation of the positions of other sampling stations along the shear zone. The Tonala shear zone is a strikingly linear feature, extending for at least 120 km from exposures near Arriaga to east of Pijijiapan (Fig. 2). The Tonala shear zone is associated with high-amplitude and short-wavelength linear magnetic anomaly with a strike of ~310° that is superimposed on a longer-wavelength and somewhat irregular magnetic low extending from Tehuantepec to Pijijiapan in coastal Chiapas (Fig. 7). The linear pattern of this anomaly may be recognized between Mapastepec and Arriaga. A linear anomaly extending northwest of Arriaga with a strike of 330° is a possible north-west extension of the Tonala shear zone, possibly linking the Tonala shear zone with structures in the western Tehuantepec Gulf.

A subvertical, west-northwest–striking (295° to 320°), northeast-dipping foliation (mean trend of 319° and mean dip of 74° northeast) and sub-horizontal lineation characterize the Tonala shear zone (Figs. 8A and 8B). In the mesoscale, some delta clasts structures indicate a left-lateral sense of motion, but generally intense shear produced planar fabrics from which kinematic indicators are ambiguous. In the microscale, we observed some S-C' structures indicating right-lateral shear. Seismic motion tensors for earthquakes along the shear zone are left-lateral (Guzmán-Speziale, 2014). At an isolated locality at Los Patos railroad station (Fig. 2), the mylonite is developed in marbles of inferred Cretaceous age. White micas separated from these rocks yield a 40Ar/39Ar plateau age of 10.4 ± 0.1 Ma (Table 2). The age estimate is slightly older than hornblende and biotite 40Ar/39Ar cooling age estimates of ca. 8.2 Ma from three mylonitic gneisses east of Los Patos in the shear zone, reported by Ratschbacher et al. (2009) and interpreted by those workers to represent the age of sinistral shear deformation. Rocks along the shear zone west of Arriaga have stretching lineations to the northwest, but rocks east of Arriaga have shallow lineations varying from northwest to southeast.

Permainan granitoids north of Arriaga (Fig. 2) contain numerous, and discrete, ultramylonite bands tens of centimeters in thickness, which are cut by dikes and elongated porphyric intrusions associated with the shear zone. Kinematic analysis of features in ultramylonite zones indicates a left-lateral regime (Fig. 9C). The contacts between the dikes and the porphyritic granitoids show evidence of magma mingling, which is interpreted to indicate magmatic fracturing. Near the contact between the ultramylonite and the dikes, magmatic fabrics are overprinted or otherwise obscured by solid-state fabrics.

At two sites east of Arriaga, there are pervasive mesoscale folds with northwest-striking axial planes in granites. Axial planes in host rocks north of the shear zone between Tonala and Arriaga are similar to those within the shear zone. From a regional perspective, this observation, together with the northeast-dipping foliation planes, is consistent with northeast-directed shortening during pluton emplacement and strike-slip motion along the shear zone, thus resulting in an overall transpressional setting during shear zone activity. A continuous >200-m-wide zone of isoclinal folding evident at the mesoscale is exposed at a series of localities east of Arriaga; this zone is located at the contact between the Tonala shear zone and the Chiapas Massif (Fig. 9A). We refer to this zone as the “shear-zone contact,” for which axial planes strike northwest (mean trend of 335° and mean dip 68° to the northeast; Fig. 9B). The folds are classified as Ramsay’s class 2 folds. Contact zone folds include lower-scale folds and asymmetric folds, which show a SW-side-up shear sense.

Between Tepanatepec and Zanatepec (Fig. 2), melanocratic phyllites are exposed as screens within mylonitized granitoids. They are interpreted to be part of the Upper Cretaceous marine-dominated sequence of Tehuantepec described by Pérez-Gutiérrez et al. (2009). West of Zanatepec, the shear zone juxtaposes high-grade metasedimentary rocks to the north of the mylonites with lithic graywacke and volcanioclastic conglomerates to the south. These field relationships also suggest north-side-up thrusting, produced by transpression in the shear zone.

Coarse-grained granitoids with or without ductile deformation in and around the shear zone occasionally contain pseudotachylyte vein networks. These are generally parallel arrays, but they occasionally form conjugate arrays of veins with parasitic branching. Pseudotachylyte veins vary in thickness between ~1 and 20 mm, separated at distances between ~1 and 10 m, and with variable offsets of up to 60 cm. They have an average east-northeast–west-northwest orientation and dip steeply to the south (Fig. 9D). Our observations indicate that the pseudotachylytes are associated with extension along nearly E-W planes. They were formed at a shallower depth than the mylonite of the Tonala shear zone, and they may be associated with exhumation in a younger transtensional regime.

DISCUSSION

A suite of calc-alkaline intrusions of predominantly intermediate composition defines the Miocene Chiapanecan arc. The intrusions range in composition from mafic to felsic. The plutons have geochemical signatures typical of an arc setting (Fig. 6). The plutons exposed in the region between Zanatepec and Pijijiapan yield interpreted emplacement ages between ca. 12 and 10 Ma, and they serve to better define a regional eastward-younging trend of plutons along the southwest Mexico Pacific margin. The microscopic textures suggest that shear-zone–related deformation of the plutons was at temperatures in excess of 500 °C, which, for relatively high geothermal gradients, suggest emplacement in the middle crust. Exposures of mid-crustal-level rocks, rather than volcanic rocks as is the case in Oaxaca and Guatemala (Fig. 1), are most likely related to recent exhumation of plutons of the Pacific Chiapas margin and regional uplift. Ascent of magma was most likely facilitated and controlled by the active Tonala shear zone, a crustal discontinuity along the southern margin of the Chiapas Massif. This is suggested by the distribution of plutons, their elongated shape, and...
Figure 6. Geochemical data for Miocene rocks of coastal Chiapas. (A) Trace-element multi-element spider diagram, with mid-ocean-ridge-basalt (MORB)–normalized values after Sun and McDonough (1989). (B) MORB-normalized rare earth element data.
the syngenetic relationship between dikes and ultramylonite. Based on the
geochronologic data reported here, as well as previously published data, we
infer that emplacement of magma was synchronous with strike-slip motion
in the Tonalá shear zone. Interpreted crystallization ages of plutons of the
Miocene Chiapas arc and cooling ages of neoformed micas in the shear
zone overlap with crystallization age estimates on plutons of 10.2 Ma near
Pijijiapan and ca. 10.8 Ma near Tepanatepec, bracketing the inferred cool-
ing age of micas at Los Patos station (10.4 Ma). A $^{40}$Ar/$^{39}$Ar cooling age for
hornblende of ca. 12 Ma for the La Polka intrusion and a U-Pb zircon crys-
tallization age estimate reported by Witt et al. (2012) of ca. 12.3 Ma (their
sample C13) from the coastal plutonic suite are interpreted to indicate that
arc magmatism was active since ca. 12 Ma in the late middle Miocene in
the Tonalá area, and it likely continued until ca. 9 Ma.

The Tonalá shear zone experienced a complex history, and although spe-
cific field relations provide ambiguous kinematic information, we interpret
the collective body of information to indicate that the Tonalá shear zone
was a predominantly left-lateral transpressional structure with a component
of northeast-directed shortening. Pervasive folding of rocks at the shear-
zone contact indicates regional shortening between the Miocene granitoids
and the Chiapas Massif. Other indicators of northeast-southwest regional
contraction are the intersection of shear-zone fabrics and the orientations
do dikes, the southeast-plunging stretching lineations of the Tonalá shear
zone, as well as the steep northeast dips of the axial planes of regional folds.
Because of this, we suggest that the Chiapas Massif was displaced to the
southwest above rocks now lying below the coastal plain, and that ascent
of the Miocene plutons was associated with an attending component of
northeast-directed shortening. A similar structural relationship was inferred
by Authemayou et al. (2011) based on analysis of geomorphic features, and
was implied earlier by Guzmán-Speziale and Meneses-Rocha (2000) in
their investigation of the North America–Caribbean plate boundary.

The Pacific margin of Mexico from ~106°W to the Tehuantepec isthmus
at ~94°W is characterized by wide exposures of Mesozoic metavolca-
nic arc sequences and metasedimentary rocks of Jurassic and Cretaceous
protolith ages, and these rocks are intruded by Late Cretaceous to Mio-
cene plutons (Talavera-Mendoza et al., 2013; Ducea et al., 2004; Morán-
Zenteno et al., 2000; Herrmann et al., 1994). The Cretaceous to Miocene
intrusions, as well as regional metamorphism, overprint a previously
assembled mosaic of older tectonic elements defined by Campa and Coney
Chiapas Miocene plutons along the Tonalá shear zone

The plutons along the coast become progressively younger toward the southeast (Herrmann et al., 1994; Morán-Zenteno et al., 2000; Fig. 1), with ages of ca. 90 Ma near Puerto Vallarta at 106°W (Fig. 1, inset; Köhler et al., 1988), ages of ca. 60–70 Ma near Colima at ~104°W, ages of ca. 45 Ma near Zihuatanejo at ~101.5°W (Martini et al., 2010), and ages of ca. 13 Ma in the Tehuantepec region (Damon and Montesinos, 1978). Miocene plutons in coastal Chiapas and Oaxaca, as described here and in other reports, clearly extend the eastward-younging trend of calc-alkaline magmatism observed along the Pacific coast of Mexico, with crystallization ages of ca. 10 Ma in the Tonalá area. The U-Pb crystallization ages of plutons, when plotted against distance along the continental margin measured from an arbitrary point in Puerto Vallarta, as selected in previous work by Schaaf et al. (1995) among others (Fig. 10), show a systematic decrease from west to east, with magmatism migrating eastward at a rate of ~30 km/m.y.

The east-directed decrease in the age of plutons in the continental margin (shown in Fig. 1; quantified in Fig. 10) has been interpreted to reflect eastward migration of the trench-transform-trench triple junction formed by the Middle America Trench and a fault system that accommodated eastward motion of the Caribbean plate. This left-lateral strike-slip fault system parallel to the modern continental margin accommodated Caribbean–North America plate motion from Eocene to Miocene time (Karig et

Figure 8. (A) Structural data along the Tonalá mylonite belt. Small stereoplots show foliation planes at selected stations along the shear zone, with large hexagon symbol showing mean lineation where clearly present. Foliations show a relatively constant northwest strike along the shear zone. (B) Stereoplot of poles of foliation (open circles) and stretching lineation (closed circles) for all stations where these data were collected. They show the full variability of structural data along the shear zone.

(1983) as the Guerrero, Mixteco, Oaxaca, and Maya terranes (Fig. 1).
Figure 9. Structural observations: (A) Isoclinal fold at the contact zone between the Tonalá shear zone and the Chiapas Massif. (B) Stereoplot of northwest-trending mean axial fold plane corresponding to poles of the folds delineating the contact zone (open circles) and southeast-plunging hinge lines (closed circles). (C) Stereoplot of poles (open circles) and great circles of ultramylonite planes, including slip directions (black circles with arrows) and fault plane solution. (D) Stereoplot of poles (open circles) and great circles of pseudotachylyte planes, including slip directions (black circles with arrows) and fault plane solution.
Chiapas Miocene plutons along the Tonalá shear zone

Figure 10. Plot of age (U-Pb, various methods) vs. distance (measured from the city of Puerto Vallarta along the coast) for plutons in western Mexico from Zihuatanejo, Guerrero, to Tonalá, Chiapas. The plot includes a simple linear regression fit for which the slope is $-0.0335$ and $R^2 = 0.883$. Figure was constructed with data reported by Morán-Zenteno et al. (2007), supplemented with data from Solari et al. (2007), Martini et al. (2010), and from this study.

The presence of plutonic arc rocks less than 100 km from the present Mid-America Trench, and thus the absence of a forearc region, has been interpreted as evidence of truncation of the continental margin in the Cenozoic. A component of subduction erosion has also been invoked to explain the absence of a forearc (Morán-Zenteno et al., 1996), and most likely played an important role in the removal of continental crust from the forearc region (Keppie et al., 2012).

A series of margin-parallel regional shear zones such as the Tierra Colorada (Solari et al., 2007; Rüller et al., 1992), Chacalapa (Tolson, 2005), and Tonalá (described in this study) has been interpreted to support the model of truncation of the continental margin resulting from eastward displacement of the Caribbean plate (Pindell et al., 1988). The Tonalá shear zone is the youngest mylonite belt along the margin, being active until motion was finally transferred to the Polochic-Motagua system and faults north of the Chiasas Massif after ca. 8 Ma (Guzmán-Speziale and Meneses-Rocha, 2000; Authemayou et al., 2011). We propose that the transfer of motion from the Chacalapa fault, active in the Oligocene between 29 and 24 Ma, to the Tonalá shear zone, active in the late Miocene from ca. 12 to 8 Ma, resulted in important, regionally interconnected events in the Tehuantepec area. These include left-lateral strike slip on the Chipehua fault (Fig. 1) in the western Tehuantepec Gulf (Sánchez-Barreda, 1981); widespread normal faulting in the western Tehuantepec isthmus associated with a pulse of Miocene (24–13 Ma) magmatism in this region (Morán-Zenteno et al., 2000); uplift and denudation of the western and eastern Tehuantepec region; and transduction in the Tehuantepec Gulf, forming basins into which thick sequences of sediments derived from the uplifted region accumulated. Sánchez Barreda (1981) reported up to 4 km of sandstone, shale, and conglomerate, containing plutonic and volcanic clasts in the Tehuantepec Gulf. Although a Late Cretaceous to Holocene age was assigned to this section by Sánchez-Barreda (1981), we hypothesize that it is entirely Miocene in age. Our interpretation is based on the absence of a correlatable Upper Cretaceous-Paleogene stratigraphy onshore, the presence of thick unconsolidated Miocene conglomeratic units onshore, and the likelihood that fossils in cuttings from a single well may represent reworked material. A key factor in this interpretation is the presence of plutonic clasts, because there is evidence suggesting the Chiapas Massif was not exposed in the Paleogene (Witt et al., 2012), and no other source of exposed plutonic rocks can be found in the region for the Late Cretaceous and Paleogene.

The distribution of metamorphic rocks in the northern Chortis block suggests that in the process of continental truncation, continental fragments may have been sheared along the transform systems between Chortis and Mexico, they may have been left stranded along the margin, or they may have been captured by Chortis and transported eastward, as has been suggested for the Las Ovejas complex (Torres-de León et al., 2012). The eastern area of the Tehuantepec Gulf differs from the continental margin to the west, thus south of the Xolapa terrane (Fig. 1), in that a forearc is preserved, and it is similar in size to that observed in the Central American arc (Authemayou et al., 2011). The forearc in Chiapas may be a stranded fragment of Chortis continental crust. If a forearc is still preserved south of the Miocene arc in Chiapas, this suggests that subduction erosion has not affected the Chiapas region, perhaps because of the young age of the subduction process in this area.

Paleogeographic reconstructions place the Chortis block south of the Mexican continental margin during Paleogene time (Pindell et al., 1988; Schafa el al., 1995; Rogers et al., 2007; Silva-Romo, 2008), as well as south of the Xolapa terrane (Fig. 1). Most authors suggest that the process of continental truncation involved the separation of the Chortis block from southern Mexico, as Chortis moved with the Caribbean plate. If the migration of the age of magmatism in the continental margin was directly related to the rate of displacement of the Chortis block, then the rate of motion of Chortis along the margin was ~30 km/m.y. (Fig. 10). Schafa el al. (1995) and Morán-Zenteno et al. (2009) provided different rates of migration of magmatism, but in their estimate, they combined age estimates obtained using different isotopic methods, and this process may have introduced some uncertainty. The rate of 30 km/m.y. is comparable to the average spreading rate in the Cayman Trough. MacDonald and Holcombe (1978) correlated magnetic anomalies east and west of the spreading center at the trough and suggested a total opening rate of 20 km/m.y. between 2.4 Ma and the present, with a much higher 40 km/m.y. rate between 2.4 and 8.3 Ma. Rosencrantz et al. (1988) estimated an average opening rate of 15 mm/yr between 15 and 30 Ma and the present, and a faster rate of 27 mm/yr between ca. 30 and 45 Ma. Leroy et al. (2000) estimated slower rates of total opening of 17 mm/yr between 20 Ma and the present, 20 mm/yr between 26 and 40 Ma, and an average of 15 mm/yr between 42 and 49 Ma. We recognize, however, that magmatism along the continental margin is not only dependent on the rate of displacement of the Chortis block along southern Mexico.

The modern Chiapanecan arc (Pliocene to Holocene) is located in the central Chiapas Highlands (Mora et al., 2012; Manea and Manea, 2006), some 150–200 km north of the Miocene arc and ~150 km farther inboard from the Mid-America Trench (Fig. 1). We propose that recent migration of arc magmatism to the north is due to interaction among the Cocos, North America, and Caribbean plates, with the latter represented by the Chortis block (the continental component of the Caribbean plate). This northward migration of the locus of magmatism may be explained by a decrease in the slab dip angle as the Chortis block is removed from the forearc region. The same process was proposed by Morán-Zenteno et al. (1996) to explain uplift and exhumation of midcrustal plutons of the Xolapa terrane along the Pacific coast. The displacement of the Chortis...
block explains the eastward migration of magmatism observed along the southern Mexican Pacific coast, and also the age of mylonites parallel to the margin. This includes the Tierra Colorada shear zone (also known as La Venta fault, active before 35 Ma), the Chacalapa fault (active between 29 and 24 Ma), and the ca. 13–8 Ma Tonalá fault (Fig. 1).

In this contribution, we have described a belt of middle to late Miocene plutons, and their host rocks, which are pervasively sheared along a well-defined west-northwest–trending mylonitic shear zone extending for at least 120 km (but possibly up to 150 km) along the western margin of the Chiapas Massif (Fig. 2). The position of the middle to late Miocene arc are along the Pacific coast of Chiapas, and the inland migration of magmatism during the Pleistocene are features similar to those proposed for the Xolapa area, but there are some differences. The dip of the subducted slab must increase gradually to the east in Chiapas as “normal” subduction is ongoing under the Caribbean plate in Guatemala. As in the Xolapa terrane, slab flattening results in isostatically driven uplift and exhumation of previously formed midcrustal plutons. At the trailing edge of the eastward-moving Chortis block, however, transtension has led to basin development, as observed in the Tehuanutepac area.

The 40Ar/39Ar age spectra obtained from K-feldspar in sample 34-TEP (a mylonitic monzonite north of Tepanatepec) yield a cooling age estimate that is ~1 m.y. younger than the U-Pb zircon crystallization age estimate. Using a closure temperature of the U-Pb system of ~750 °C and a maximum closure temperature of 300 °C for the 40Ar/39Ar system in K-feldspar (e.g., Heizler and Harrison, 1988), this set of data implies a rapid, minimum, cooling rate of ~450 °C/m.y. Witt et al. (2012) reported an apatite fission-track and (U-Th)/He apatite age of ca. 8.9 Ma for a locality within 0.5 km of our 34-TEP sample, suggesting that plutons of the Miocene arc were at shallow crustal levels soon after emplacement. Regional uplift in southern Chiapas probably continues today, as all rivers in the Chiapas Massif incise on bedrock. Locally, higher uplift rates may be linked to fault relays such as the link between Tonalá and Polochic driving the Chicomuselo uplift in Chiapas (Fig. 1), or at restraining bends (Authemayou et al., 2011). Uplift and erosion of the Chiapas Massif have also been responsible for sediment transport to the Gulf of Mexico since the early Miocene, but more significantly since the late Miocene. Sediment removal in the humid Chiapas climate and concomitant isostatic rebound further contribute to modern uplift.

The orientation of the Tonalá shear zone is somewhat oblique to the trace of the Polochic-Motagua fault system (Fig. 1). The Polochic-Motagua system forms an arc concave to the north, which, at its westernmost extreme, has an approximate east-west strike. This suggests a minor adjustment in relative plate motion for the North America–Caribbean plate boundary after ca. 8 Ma. Northwest-oriented left-lateral transpressional displacement along the Tonalá shear zone gradually rotated in orientation to west-northwest slip and transtensional displacement recorded by the orientation of pseudotachylite vein networks (Fig. 9D). The termination of the Tonalá shear zone acted as a fault jog, transferring part of the North America–Caribbean plate motion to faults in central Chiapas, as suggested by Guzmán-Speziale and Meneses-Rocha (2000).

According to Ratschbacher et al. (2009), the North America–Caribbean plate boundary has accommodated ~1100 km of relative displacement since ca. 45 Ma; of that, ~300 km occurred since ca. 15 Ma. Thus, relative Caribbean–North America plate motion was accommodated during the time interval over which the Tonalá shear zone was active. Relative plate motion is accommodated by distributed deformation over a large area, including strike-slip faults in Sierra Chiapas (Meneses-Rocha, 2001; see Fig. 1), normal faults in north-south grabens south of the Polochic-Motagua fault systems (e.g., Rogers and Mann, 2007; Burkart and Self, 1985; Guzmán-Speziale, 2001), and strike-slip along the major faults Polochic, Motagua, and Jamalecón, as well as other faults (Guzmán-Speziale, 2010). Burkart et al. (1987) showed that the Polochic fault accommodated ~130 km of the total displacement along the plate boundary, but Brocard et al. (2011) suggested that most of the displacement along the Polochic fault occurred prior to 7–10 Ma. We interpret the mylonite system of the Tonalá shear zone to be a relict transform boundary slightly oblique to the Polochic-Motagua fault system, which accommodated a minimum of 100 km of displacement between the Chortis block (on the Caribbean plate) and Chiapas (on the North America plate) in late Miocene time.

The structural data from the Tonalá shear zone provide strong evidence for northeast-directed shortening. This strain was contemporaneous with emplacement of the Chiapas Massif and suggests that the late Miocene Chiapas fold belt north of the Chiapas Massif (Fig. 1), and similar-age structures in the Tabasco coastal plain buried by younger sediments are kinematically linked to the Miocene interaction between the Chortis and Maya blocks along the Tonalá shear zone.

CONCLUSIONS

The Miocene Chiapanecan magmatic arc was active in the region of coastal Chiapas between ca. 13 and 9 Ma. Magma ascent and pluton emplacement were most likely controlled by a crustal-scale shear zone, herein formally named the Tonalá shear zone, which accommodated relative plate motion between the Caribbean and North America plates in the late Miocene. The shear zone is a strikingly linear feature, extending for at least 120 km, and it is characterized by the Tonalá mylonitic belt. The plutons of the Miocene arc are syntectonic, as pluton crystallization ages and ages of neofomed micas in the shear zone are indistinguishable. The Tonalá shear zone and associated rocks show evidence of very rapid uplift, which may be explained by flattening of the subducted slab as the Chortis block was displaced eastward from the forearc region. Isostatic rebound related to erosion further contributed to contemporaneous uplift.

ACKNOWLEDGMENTS

This research was possible with the support of the Conacyt grant CB129862 to R. Molina, and an American Chemical Society–Petroleum Research Fund award to T. Wayrzyniec. Antonio Godínez and Linda Donohoo assisted with sample collection. We appreciate the technical support of Olívia Pérez and Juan Tomás Vázquez. Intodo would like to thank Míck Kunik for supervision undertaking the 40Ar/39Ar experiments. In addition, Joe Wooden is thanked for his supervision of the U-Pb sensitive high-resolution ion microprobe–reverse geometry analyses. We also thank the reviewers J. Goode, M. Guzmán-Speziale, T. Simon-Labric, and an anonymous reviewer.

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MANUSCRIPT RECEIVED 30 JULY 2014
REVISED MANUSCRIPT RECEIVED 22 NOVEMBER 2014
MANUSCRIPT ACCEPTED 23 FEBRUARY 2015
Printed in the USA