Mid-Tertiary cooling ages in the Precambrian Oaxacan Complex of southern Mexico: indication of exhumation and inland arc migration

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ABSTRACT

In southern Mexico, the ~1 Ga Oaxacan Complex is in fault contact with the Mesozoic–Cenozoic Chatino terrane. ^{40}Ar/^{39}Ar dating of minerals from hornblende gneiss and quartz monzonitic gneiss in the southern Oaxacan Complex collected, 10 km and 1 km north of the Oaxaca–Xolapa boundary, yielded the following data, respectively: (1) a plateau age of 584 ± 10 Ma in hornblende and a pseudoplateau age of 23 ± 3 Ma in biotite; and (2) a plateau age of 42 ± 3 Ma in biotite, and a maximum age of 36 ± 1 Ma in K-feldspar. These are inferred to date cooling through ~500–550° C for hornblende, ~280° C for biotite, ~220° C for plagioclase, and ~310–270° C for K-feldspar. The ~582 Ma age is much younger than cooling ages from the northern Oaxacan Complex, suggesting that it records resetting during a Neoproterozoic Brasiliano tectonothermal event. On the other hand, the Tertiary cooling ages suggest reheating adjacent to either ~40 Ma or 35–25 Ma Tertiary plutons: ~42 Ma and ~23 Ma biotite ages, respectively. The former was followed by rapid cooling through ~310–270° C by ~36 Ma and exhumation before deposition of Miocene volcanic rocks. We relate these cooling ages to northward migration of the magmatic arc during the Oligocene–Miocene as a consequence of flattening of the subduction zone due to subduction erosion.

Key words: Oaxacan Complex, cooling ages, Precambrian, Tertiary, arc magmatism.

RESUMEN

En el sur de México, el Complejo Oaxaqueño de aproximadamente 1 Ga de edad está en contacto tectónico con el terreno Chatino (Complejo Xolapa) del Mesozoico–Cenozoico. El fechamiento ^{40}Ar/^{39}Ar de minerales de un gneiss de hornblenda y de un gneiss cuarzomonzonítico tomados del Complejo Oaxaqueño sur, a 10 y 1 km al norte del límite Oaxaqueño-Xolapa, dio respectivamente los resultados siguientes: (1) una edad de meseta para la hornblenda de 584 ± 10 Ma, y una edad de pseudomeseta de 23 ± 3 Ma para la biotita; y (2) una edad de meseta de 42 ± 3 Ma para biotita, y una edad máxima de 36 ± 1 Ma para el feldespato potásico. Se infiere que los datos de hornblenda fechan un enfriamiento hasta ~500–550º C para hornblenda, de ~280º C para biotita, ~220º C para plagioclasa y ~270–310º C para el feldespato potásico. La edad aproximada de 584 Ma es mucho más joven que las edades de enfriamiento del Complejo Oaxaqueño norte, sugiriendo que se registró una rehomogeneización térmica durante el evento tectónico Brasiliano del Neoproterozoico. Por otra parte, las edades terciarias de enfriamiento sugieren un recalentamiento asociado ya sea con los plutones de ~40 o los de 35–25 Ma, representados *respectivamente por las edades de biotita de ~42 y ~23 Ma. El evento más antiguo fue seguido por enfriamiento rápido hasta ~310–270º C hace aproximadamente 36 Ma, y luego exhumación antes del depósito de las rocas volcánicas del Mioceno. En este trabajo se relacionan estas edades de enfriamiento con la migración hacia el norte del arco magmático del Oligoceno–Mioceno provocado por la diminución del ángulo de subducción, a su vez resultado de un proceso de erosión por subducción.*

Palabras clave: Complejo Oaxaqueño, edades de enfriamiento, Precámbrico, Terciario, magmatismo de arco.

INTRODUCTION

The Mesozoic and Cenozoic history of Mexico is dominated by the presence of a volcanic arc produced by subduction of the Farallon Plate and its daughters (de Cserna, 1989). However, the Late Cretaceous–Oligocene arc is truncated by the southern coast of Mexico, a feature that has been attributed to two causes: (1) eastward migration of the Chortis block (Honduras) relative to southern Mexico (*e.g.*, Schaaf *et al.*, 1995), and (2) subduction erosion (Morán-Zenteno *et al.*, 1996).

The inferred migration of the Chortis block has been linked to eastward migration of the Cocos–Caribbean–North American triple junction along the southern margin of Mexico. This would produce a diachronous switch from a transform fault, with little or no relative uplift, to a subduction zone that would induce uplift and erosion. This eastward propagating uplift would be accompanied by eastward propagation of the arc. Although the latter appears to be confirmed by age data produced by Herrmann *et al.* (1994), recent data show no evidence of diachronism in arc magmatism or uplift (Ducea *et al.*, 2003; Shoemaker *et al.*, 2003).

On the other hand, subduction erosion, whereby the overriding slab is progressively removed by subduction, is generally associated with flat-slab subduction, limited trench sediment, inland migration of the arc, the deformation front, and uplift and erosion (Stern, 1991; Ramos *et al.*, 2002). Such a mechanism is consistent with an alternative reconstruction presented by Keppie and Morán-Zenteno (2003) in which the Chortis block is located southwest of its present position in the Eocene rotating northeastwards along the Cayman Transform during the Cenozoic. This would be accompanied by subduction erosion of a wedge-shaped area off southern Mexico.

As part of a project to study the Precambrian and Paleozoic rocks of Mexico, samples were collected for ^{40}Ar/^{39}Ar analysis in the southern part of the ~1 Ga Oaxacan Complex in southern Mexico, close to the fault contact with the adjacent Chatino Terrane (Figure 1). Although hornblende yielded a Late Proterozoic age, the other minerals (biotite, plagioclase and K-feldspar) yielded Tertiary ages. These Tertiary ages are evaluated in the context of current tectonic models for the Cenozoic of southern Mexico.

GEOLOGICAL SETTING

The central axis of Mexico is underlain by ~1 Ga rocks, which constitute the basement of a microcontinent that has been named Oaxaquia after the Oaxacan Complex that forms the basement of the Zapoteco Terrane of southern Mexico (Figures 1, 2) (Ortega-Gutiérrez *et al.*, 1995, 1999). Geochronological and petrological data from the Oaxacan Complex indicate a complex sequence of events including: (1) ~1,235–1,117 Ma arc magmatism; (2) ~≥1,170–1,117 Ma intrusion of rift-related, supra-subduction zone granite; (3) ~1,012 Ma intrusion of an anorthosite–mangerite–charnockite–granite suite; and (4) ~1000–975 Ma granulite-facies metamorphism accompanied by polyphase deformation (Keppie *et al.*, 2001, 2003; Cameron *et al.*, in press). The northern Oaxacan Complex is unconformably overlain by earliest Ordovician rocks (Robison and Pantoja-Alor, 1968), whereas the southern Oaxacan Complex is unconformably overlain by (?)Jurassic red beds and ≤500 m Cretaceous platformal carbonate rocks and flysch. During the Late Cretaceous–Early Tertiary, these rocks were involved in NE-vergent thrusting and folding associated with the Laramide Orogeny (de Cserna, 1989). Paleogene continental red beds and Tertiary (mainly Miocene) calcalkaline volcanic arc rocks lie unconformably on these older sequences (Morán-Zenteno *et al.*, 1999).

In fault contact to the south of the Oaxacan Complex lies the Chatino Terrane (Figure 1), essentially composed of a poly-deformed quartzo-feldspathic sequence (Xolapa Complex) that was migmatized in Late Jurassic–Early Cretaceous time (132 ± 2 Ma lower intercept, U–Pb age of nearly concordant zircons; Herrmann *et al.*, 1994; Ducea *et al.*, 2003). This sequence was intruded by a suite of Oligocene, calcalkaline plutons that were reported to become progressively younger eastwards along the coast from ~35 Ma west of Acapulco to ~27 Ma near Huatulco (Herrmann *et al.*, 1994). Two exceptions to this general trend

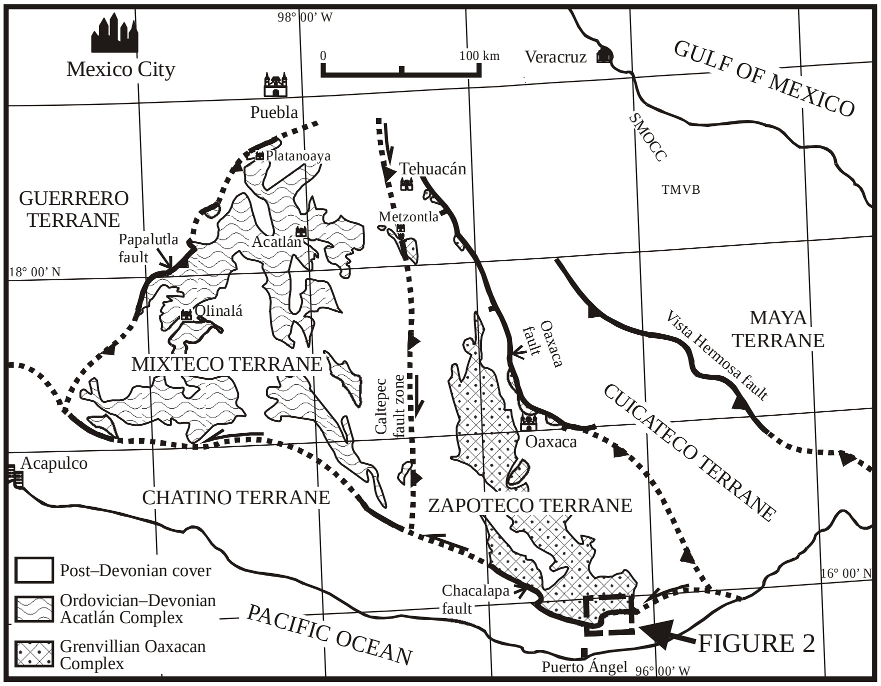

Figure 1. Terrane map of southern Mexico showing the location of the study area (modified after Ortega-Gutiérrez *et al.*, 1999).

lie just south of the study area: (1) the 29 ± 1 Ma Huatulco pluton (concordant U–Pb zircon age; Herrmann *et al.*, 1994); and (2) the 40 ± 2 Ma Puerto Angel deformed pluton (concordant U–Pb zircon age; Robinson, 1990). These exceptions may be more common because Ducea *et al.* (2003) indicate that there is no eastward migration in the magmatism. Hornblende and mica ages are generally 1–5 my younger than the zircon ages indicating that the plutons cooled quickly (Herrmann *et al.*, 1994; Schaaf *et al.*, 1995; Morán-Zenteno *et al.*, 1996, 1999). Morán-Zenteno *et al.* (1996) calculated that the ~29 Ma Huatulco pluton was exhumed during the Oligocene from 20 km depth at a rate of ~0.7 km/my. This exhumation rate is well above the maximum surface weathering rates of 0.25 km/my (Harley, 1992) and an additional component of tectonic erosion is inferred, a conclusion consistent with the core complex structure inferred for the Xolapa Complex by Robinson (1990). A post-12 Ma exhumation rate of 0.34 km/my is recorded in apatite fission track ages and (U–Th)/He ages (Shoemaker *et al.*, 2003).

EXPERIMENTAL PROCEDURES

Amphibole, biotite, and feldspar mineral grains were separated from two samples, a hornblende gneiss and a quartz monzonite, collected near the southern margin of the Oaxacan Complex (Figure 2). These minerals were pre-treated and concentrated by standard techniques and later selected by handpicking under a binocular microscope from fractions that ranged in size from 40–60 mesh at the mineral separation laboratory at Centro de Geociencias–UNAM, Campus Juriquilla, Querétaro, Qro. Mineral separates were loaded into Al-foil packets and irradiated together with Hb3GR as a neutron-fluence monitor at the McMaster Nuclear Reactor (Hamilton, Ontario). ^{40}Ar/^{39}Ar analyses were performed by standard laser step-heating techniques described in detail by Clark *et al.* (1998) at the Geochronology Research Laboratory of Queen's University, Kingston, Ontario, Canada. The data are given in Table 1 and plotted in Figure 3. All data have been corrected for blanks, mass discrimination, and neutron-induced interferences. For the purposes of this paper, a plateau age is obtained when the apparent ages of at least three consecutive steps, comprising a minimum of 55% of the ^{39}Ar$_k$ released, agree within 2σ error with the integrated age of the plateau segment. We further define a so-called "pseudoplateau", which follows the requirement of a plateau age, but has a ^{39}Ar$_k$ percentage that can be lower than 55%. Errors shown in Table 1 and on the age spectrum and isotope-correlation diagrams represent the analytical precision at ±2σ.

RESULTS

Hornblende gneiss interbanded with psammitic and pelitic granulites was sampled for analysis (CS100-99). It consists of hornblende, plagioclase, garnet, and pyroxene with accessory apatite, hematite, ilmenite, spinel and zircon.

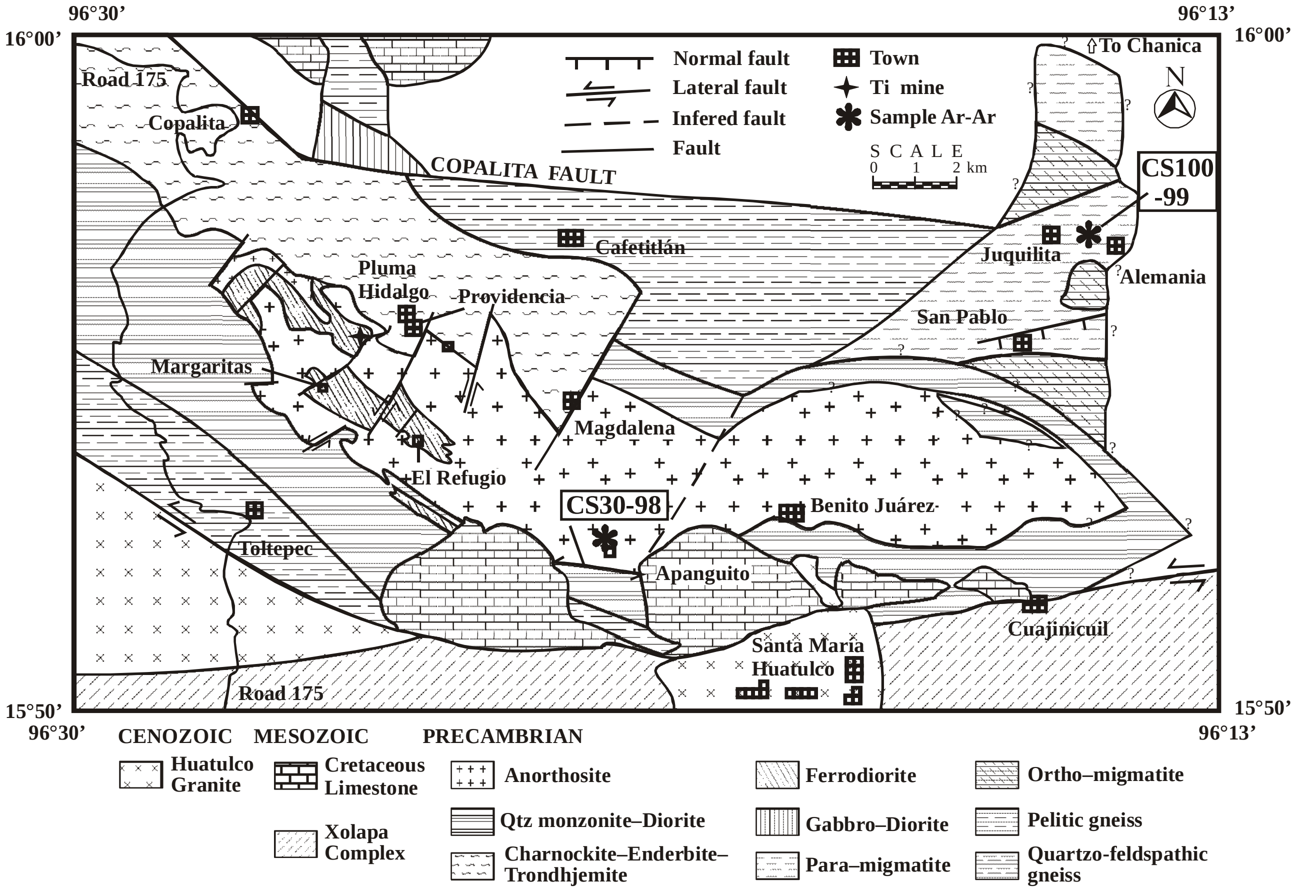

Figure 2. Geological map of the southern Oaxacan Complex showing sample locations.

Table 1. ^{40}Ar/^{39}Ar laser step-heating data for samples from the southern Oaxacan Complex.

AOR-L-89: CS100-99 Hornblende

J Value	Mass	Volume ^{39}K	Integrated Age	Can/Pos	Run date	Printed
0.007218 ± 0.000060	21.0 mg	0.05x10^{-10} cm^3 NTP	707.93 ± 8.55 Ma	166/P5	2000/08/24	2003/05/23

Plateau Age: 584.12 ± 9.74 Ma (60.4% of ^{39}Ar, steps marked by <)
Initial 40/36: 4761.91 ± 8696.63 (MSWD = 0.27, isochron between -0.41 and 3.83)
Correlation Age: 541.72 ± 413.50 Ma (39.6% of ^{39}Ar, steps marked by >)

Power	^{36}Ar/^{40}Ar	^{39}Ar/^{40}Ar	r	Ca/K	% ^{40}Ar$_{Atm}$	% ^{39}Ar	^{40}Ar*/^{39}K	Age
2.00>	0.000178 ± 0.000049	0.002904 ± 0.000115	0.113	2.981	5.25	5.27	326.276 ± 13.052	2183.79 ± 50.66
3.00>	0.000056 ± 0.000098	0.017534 ± 0.000306	0.017	4.707	1.66	13.26	56.085 ± 1.907	613.22 ± 17.68
5.00>	0.000007 ± 0.000103	0.021244 ± 0.000303	0.029	7.579	-0.21	21.06	47.173 ± 1.561	528.67 ± 15.16
<5.75	0.000013 ± 0.000079	0.018215 ± 0.000246	0.050	7.565	0.37	22.90	54.696 ± 1.445	600.30 ± 13.49
<6.60	0.000022 ± 0.000360	0.020623 ± 0.000799	0.005	6.882	-0.65	5.55	48.802 ± 5.497	544.42 ± 52.93
<7.00	0.000014 ± 0.000060	0.018984 ± 0.000214	0.064	7.369	0.41	31.97	52.457 ± 1.067	579.28 ± 10.07

Power	^{40}Ar	^{39}Ar	^{38}Ar	^{37}Ar	^{36}Ar	Blank ^{40}Ar	Atmos 40/36
2.00>	0.942 ± 0.005	0.004 ± 0.000	0.001 ± 0.000	0.002 ± 0.000	0.000 ± 0.000	0.003	292.368
3.00>	0.394 ± 0.003	0.008 ± 0.000	0.001 ± 0.000	0.008 ± 0.000	0.000 ± 0.000	0.003	292.368
5.00>	0.516 ± 0.003	0.012 ± 0.000	0.002 ± 0.000	0.020 ± 0.000	0.000 ± 0.000	0.003	292.368
<5.75	0.653 ± 0.004	0.013 ± 0.000	0.002 ± 0.000	0.022 ± 0.000	0.000 ± 0.000	0.003	292.368
<6.60	0.142 ± 0.001	0.004 ± 0.000	0.001 ± 0.000	0.005 ± 0.000	0.000 ± 0.000	0.003	292.368
<7.00	0.875 ± 0.004	0.018 ± 0.000	0.003 ± 0.000	0.030 ± 0.000	0.000 ± 0.000	0.003	292.368

Table 1. Continued.

AOR-159: CS100-99 Biotite

J Value	Mass	Volume ^{39}K	Integrated Age	Can/Pos	Run date	Printed
0.007218 ± 0.000060	19.0 mg	5.18x10^{-10} cm^3 NTP	47.06 ± 2.50 Ma	166/P4	2001/03/06	2002/11/01

Plateau Age: 23.39 ± 3.61 Ma (55.4% of ^{39}Ar, steps marked by <); 133.56 ± 5.06 Ma (18.6% of ^{39}Ar, steps marked by [ )
Initial 40/36: 341.42 ± 463.66 (MSWD = 0.72, isochron between -0.41 and 3.83)
Correlation Age: 21.18 ± 5.63 Ma (55.4% of 39Ar, steps marked by >)

Power	^{36}Ar/^{40}Ar	^{39}Ar/^{40}Ar	r	Ca/K	% ^{40}Ar$_{Atm}$	% ^{39}Ar	^{40}Ar*/^{39}K	Age
<1.00>	0.003061 ± 0.001486	0.048886 ± 0.003318	0.321	12.402	90.22	1.36	1.973 ± 7.613	25.51 ± 97.74
<3.00>	0.001411 ± 0.000536	0.278316 ± 0.002133	0.013	0.835	41.25	16.06	2.099 ± 0.565	27.12 ± 7.24
<5.00>	0.000463 ± 0.000334	0.514833 ± 0.002970	0.003	0.323	13.35	37.97	1.679 ± 0.191	21.73 ± 2.46
7.00	0.000192 ± 0.000424	0.361164 ± 0.002272	0.003	0.567	5.53	26.00	2.614 ± 0.346	33.72 ± 4.43
[8.00	0.000047 ± 0.000139	0.092673 ± 0.000629	0.094	1.551	1.34	18.61	10.646 ± 0.409	133.56 ± 4.95

Power	^{40}Ar	^{39}Ar	^{38}Ar	^{37}Ar	^{36}Ar	Blank ^{40}Ar	Atmos 40/36
<1.00	1.509 ± 0.009	0.102 ± 0.004	0.020 ± 0.003	0.012 ± 0.002	0.010 ± 0.000	0.069	286.044
<3.00>	3.069 ± 0.009	0.863 ± 0.006	0.040 ± 0.003	0.010 ± 0.002	0.010 ± 0.000	0.057	286.044
<5.00>	3.932 ± 0.010	2.002 ± 0.010	0.069 ± 0.004	0.009 ± 0.002	0.006 ± 0.000	0.053	286.044
7.00	3.821 ± 0.009	1.378 ± 0.008	0.052 ± 0.003	0.009 ± 0.002	0.005 ± 0.000	0.052	286.044
[8.00	10.472 ± 0.017	0.989 ± 0.006	0.054 ± 0.004	0.013 ± 0.002	0.005 ± 0.000	0.050	286.044

AOR-208: CS30-98 Biotite

J Value	Mass	Volume ^{39}K	Integrated Age	Can/Pos	Run date	Printed
0.007168 ± 0.000066	23.0 mg	3.07x10^{-10} cm^3 NTP	42.45 ± 3.24 Ma	166/P1	2001/03/16	2002/03/14

Plateau Age: 41.55 ± 7.23 Ma (100.0% of ^{39}Ar)
Initial 40/36: 300.48 ± 270.04 (MSWD = 1.12, isochron between -0.41 and 3.83)

Power	^{36}Ar/^{40}Ar	^{39}Ar/^{40}Ar	r	Ca/K	% ^{40}Ar$_{Atm}$	% ^{39}Ar	^{40}Ar*/^{39}K	Age
2.00	0.002127 ± 0.000438	0.119473 ± 0.001374	0.069	0.603	62.59	13.46	3.112 ± 1.040	39.80 ± 13.15
5.00	0.000834 ± 0.000258	0.218978 ± 0.001405	0.014	0.198	24.43	44.48	3.444 ± 0.344	43.99 ± 4.34
8.00	0.000459 ± 0.000316	0.265343 ± 0.001751	0.009	0.188	13.41	42.06	3.259 ± 0.350	41.67 ± 4.42

Power	^{40}Ar	^{39}Ar	^{38}Ar	^{37}Ar	^{36}Ar	Blank ^{40}Ar	Atmos 40/36
2.00	3.564 ± 0.011	0.447 ± 0.004	0.025 ± 0.002	0.007 ± 0.001	0.012 ± 0.000	0.088	286.044
5.00	6.375 ± 0.014	1.408 ± 0.008	0.052 ± 0.003	0.007 ± 0.002	0.010 ± 0.000	0.088	286.044
8.00	4.998 ± 0.012	1.332 ± 0.008	0.049 ± 0.003	0.007 ± 0.001	0.007 ± 0.000	0.086	286.044

These phases are partly replaced by epidote, chlorite, biotite, muscovite and quartz. Hornblende from this sample yielded discordant data with a plateau age of 584 ± 10 Ma in the three highest steps (Figure 3a). The old ages recorded by the lowest steps probably reflect excess argon. The apparent-age spectrum of biotite from the same sample also yielded a pseudoplateau age of 23 ± 3 Ma in the lowest steps but climbed to 134 ± 5 Ma in the last heating step (Figure 3b).

Coarse quartz monzonitic gneiss occurring at the margin of a massive anorthosite body in association with metaferrodiorite was also sampled for dating (CS30-98). It consists of pyroxene, perthite, K-feldspar, quartz, and biotite with accessory rutile, and titanite. Myrmekite formed during retrograde metamorphism. The biotite from this sample yielded concordant data with a plateau age of 42 ± 3 Ma (Figure 3c). Plagioclase from the same sample yielded discordant data with an isotope correlation age of 29 ± 44 Ma (Figure 3d), whereas K-feldspar yielded discordant data with an age of 36 ± 1 Ma in the highest step (Figure 3e). The old ages recorded by the first two steps are interpreted to reflect excess argon.

DISCUSSION

The ^{40}Ar/^{39}Ar ages (Table 1, Figure 3) presented here are considered to record cooling through closure temperatures for ^{40}Ar diffusion. These were calculated by various authors using grain size and estimated rate of cooling in hornblende at ~520–580^{o} C (Harrison, 1981); in biotite

Table 1. Continued.

AOR-L-207: CS30-98 Plagioclase

J Value	Mass	Volume ^{39}K	Integrated Age	Can/Pos	Run date	Printed
0.007201 ± 0.000062	22.0 mg	16.61x10^{-10} cm^{3} NTP	241.85 ± 2.58 Ma	166/P3	2001/03/16	2002/11/01

Plateau Ages: 529.15 ± 7.15 Ma (15.6% of ^{39}Ar, steps marked by <); 97.21 ± 1.54 Ma (57.8% of ^{39}Ar, steps marked by [ ); 86.22 ± 3.54 Ma (15.0% of ^{39}Ar, steps marked by {)
Initial 40/36: 1740.03 ± 4431.86 (MSWD = 0.40, isochron between 0.42 and 2.15)
Correlation Age: 28.76 ± 43.87 Ma (84.4% of ^{39}Ar, steps marked by >)

Power	^{36}Ar/^{40}Ar	^{39}Ar/^{40}Ar	r	Ca/K	% ^{40}Ar$_{Atm}$	% ^{39}Ar	^{40}Ar*/^{39}K	Age
1.00>		ERR						
2.00>	0.000476 ± 0.000638	0.003369 ± 0.001614	0.993	5.340	14.04	0.92	55.127 ± 10.907	881.32 ± 49.94
3.00>	0.000532 ± 0.000213	0.012093 ± 0.000535	0.896	12.952	15.70	1.83	69.702 ± 1.989	733.81 ± 17.20
4.00>	0.000432 ± 0.000195	0.059338 ± 0.000582	0.281	10.719	12.72	3.67	14.706 ± 0.804	181.59 ± 9.44
5.00>	0.000519 ± 0.000224	0.096637 ± 0.000741	0.089	3.849	15.29	4.86	8.761 ± 0.650	110.37 ± 7.94
{6.00>	0.000490 ± 0.000237	0.130219 ± 0.000893	0.045	1.254	14.40	6.07	6.569 ± 0.523	83.38 ± 6.49
{7.00>	0.000477 ± 0.000133	0.123565 ± 0.000724	0.038	0.773	14.03	8.98	6.953 ± 0.307	88.14 ± 3.80
[8.00>	0.000422 ± 0.000041	0.113861 ± 0.000529	0.024	0.526	12.42	57.82	7.688 ± 0.106	97.21 ± 1.31
<9.00	0.000338 ± 0.000076	0.019020 ± 0.000230	0.700	6.268	9.97	15.62	47.334 ± 0.615	529.15 ± 5.96

Power	^{40}Ar	^{39}Ar	^{38}Ar	^{37}Ar	^{36}Ar	Blank ^{40}Ar	Atmos 40/36
1.00>	50.379 ± 0.071	0.068 ± 0.004	0.075 ± 0.005	0.007 ± 0.002	0.037 ± 0.000	0.034	286.044
2.00>	45.530 ± 0.077	0.200 ± 0.006	0.081 ± 0.006	0.012 ± 0.003	0.028 ± 0.000	0.147	286.044
3.00>	25.111 ± 0.038	0.341 ± 0.004	0.049 ± 0.003	0.024 ± 0.002	0.020 ± 0.000	0.099	286.044
4.00>	10.329 ± 0.017	0.645 ± 0.005	0.033 ± 0.003	0.035 ± 0.002	0.011 ± 0.000	0.091	286.044
5.00>	8.451 ± 0.016	0.844 ± 0.006	0.030 ± 0.003	0.020 ± 0.002	0.010 ± 0.000	0.087	286.044
{6.00>	7.860 ± 0.017	1.047 ± 0.006	0.030 ± 0.002	0.012 ± 0.002	0.009 ± 0.000	0.091	286.044
{7.00>	12.197 ± 0.020	1.532 ± 0.008	0.041 ± 0.003	0.011 ± 0.002	0.011 ± 0.000	0.087	286.044
[8.00>	84.719 ± 0.085	9.702 ± 0.043	0.214 ± 0.009	0.029 ± 0.004	0.042 ± 0.000	0.110	286.044
<9.00	136.236± 0.133	2.645± 0.020	0.277 ± 0.015	0.078 ± 0.005	0.055 ± 0.000	0.095	286.044

AOR-L-163: CS30-98 K-feldspar

J Value	Mass	Volume ^{39}K	Integrated Age	Can/Pos	Run date	Printed
0.007185 ± 0.000064	28.0 mg	23.42x10^{-10} cm^{3} NTP	42.55 ± 0.62 Ma	166/P2	2001/03/08	2002/11/01

Plateau Age: 36.36 ± 0.65 Ma (44.0% of ^{39}Ar, steps marked by <); 25.44 ± 4.43 Ma (4.5% of ^{39}Ar, steps marked by [ )
Initial 40/36: 1518.23 ±2694.41 (MSWD = 1.57, isochron between -0.41 and 3.83)
Correlation Age: 27.87 ± 13.48 Ma (59.1% of 39Ar, steps marked by >)

Power	^{36}Ar/^{40}Ar	^{39}Ar/^{40}Ar	r	Ca/K	% ^{40}Ar$_{Atm}$	% ^{39}Ar	^{40}Ar*/^{39}K	Age
4.00>	0.000562 ± 0.000145	0.087176 ± 0.000569	0.074	0.628	16.56	3.62	9.566 ± 0.467	119.92 ± 5.67
6.00>	0.000402 ± 0.000074	0.148646 ± 0.000709	0.014	0.708	11.74	11.50	5.934 ± 0.147	75.32 ± 1.83
[7.00	0.000291 ± 0.000545	0.463862 ± 0.003396	0.002	0.705	8.21	4.48	1.976 ± 0.347	25.44 ± 4.43
7.5	0.000275 ± 0.000053	0.349835 ± 0.001517	0.003	0.507	7.82	36.42	2.633 ± 0.046	33.81 ± 0.59
<8.00>	0.000181 ± 0.000049	0.334758 ± 0.001421	0.002	0.514	5.09	43.98	2.834 ± 0.045	36.36 ± 0.57

Power	^{40}Ar	^{39}Ar	^{38}Ar	^{37}Ar	^{36}Ar	Blank ^{40}Ar	Atmos 40/36
4.00>	9.783 ± 0.019	0.864 ± 0.005	0.018 ± 0.002	0.005 ± 0.001	0.008 ± 0.000	0.043	286.044
6.00>	18.232 ± 0.024	2.722 ± 0.012	0.162 ± 0.010	0.012 ± 0.001	0.010 ± 0.000	0.042	286.044
[7.00	2.336 ± 0.009	1.068 ± 0.006	0.065 ± 0.009	0.006 ± 0. 001	0.003 ± 0.000	0.041	286.044
7.50	24.680 ± 0.031	8.598 ± 0.035	0.501 ± 0.013	0.024 ± 0.002	0.010 ± 0.000	0.044	286.044
<8.00>	31.117 ± 0.029	10.380 ± 0.042	0.604 ± 0.014	0.030 ± 0.002	0.009 ± 0.000	0.042	286.044

at ~300–360^{o} C (Harrison *et al.*, 1985); in plagioclase at ~220^{o} C (Harrison and Clarke, 1979), and in K-feldspar at ~270–310^{o} C (Foland, 1974). The southern Oaxacan Complex must have been at the surface in mid-Mesozoic times because it is unconformably overlain by (?)Jurassic red beds and ≤500 m Cretaceous rocks (Figure 4). On the other hand, in the northern Oaxacan Complex, granulite-facies metamorphism at ~1000–975 Ma was followed by

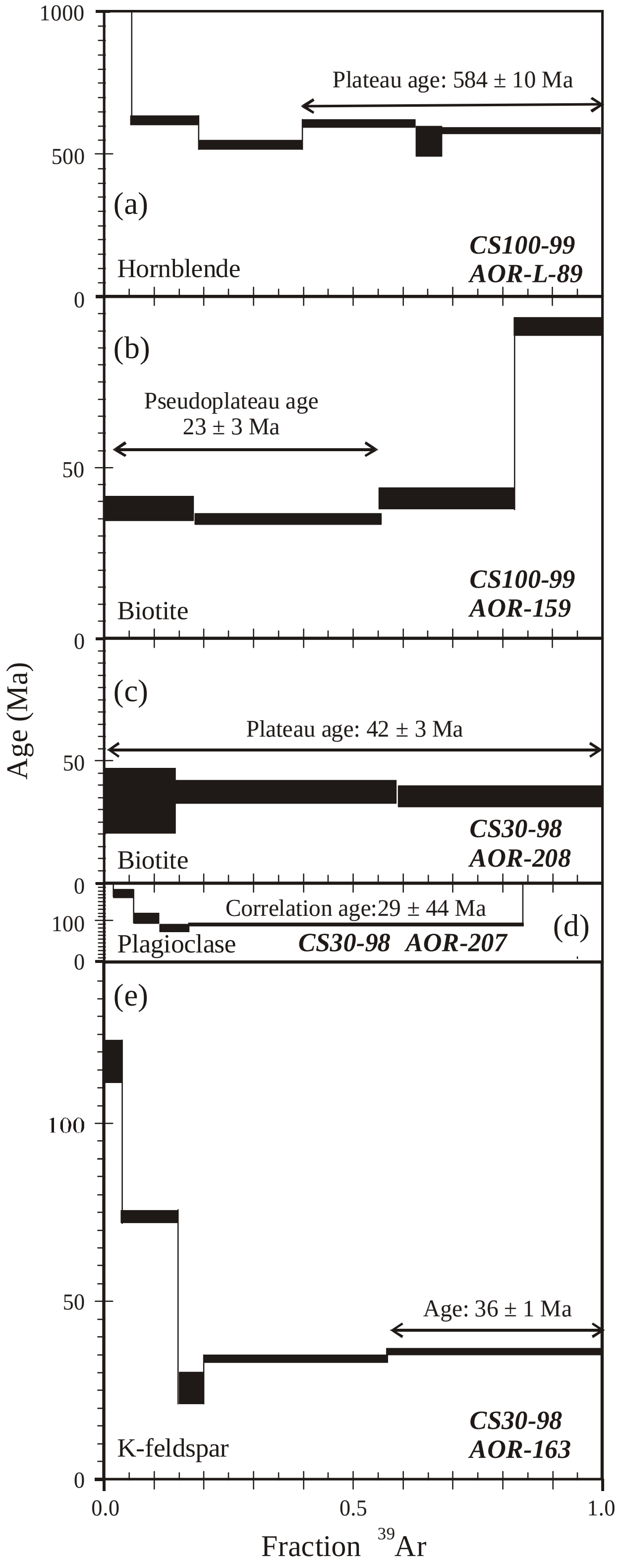

Figure 3. ^{40}Ar/^{39}Ar laser step-heating analyses plotted on Age (Ma) versus Fraction of ^{39}Ar: (a) hornblende from sample CS100-99; (b) biotite from sample CS100-99; (c) biotite from sample CS30-98; (d) plagioclase from sample CS30-98; and (e) K-feldspar from sample CS30-98. Note that large errors in the correlation age render it geological meaningless, however, the data are reported to indicate to future researchers the problems in dating plagioclase.

cooling through 500–550° C and 400° C at 977 ± 12 Ma and 945 ± 10 Ma, respectively (Keppie *et al.*, 2001 and in press; Solari *et al.*, 2003; Cameron *et al.*, in press). Such cooling is consistent with the fact that the northern Oaxacan Complex is unconformably overlain by earliest Ordovician rocks (Robison and Pantoja-Alor, 1968). If one assumes that the southern Oaxacan Complex underwent a similar cooling history, then the ~584 Ma age must reflect cooling following a Late Neoproterozoic reheating event. Similar ages have been recorded in adjacent terranes, such as in the Maya terrane to the east (Krogh *et al.*, 1993), and in the detrital zircons of the Acatlán Complex to the west (Ramírez-Espinoza *et al.*, 2002), and are common in the Brasiliano orogens of South America (Cordani *et al.*, 2000).

Given this scenario, the Tertiary ages yielded by biotite and feldspar must record late-stage reheating events. The 23 ± 3 Ma pseudoplateau age recorded in biotite from the same sample as the hornblende is inferred to reflect thermal resetting related to a magmatic event represented by the intrusion of the 29 ± 1 Ma Huatulco pluton (concordant U–Pb zircon age; Herrmann *et al.*, 1994) and related plutons that range in age from ~27 ± 1 to 20 ± 1 Ma (Rb–Sr biotite–whole rock ages by Morán-Zenteno *et al.*, 1999). This reheating could also explain the excess argon recorded by the lowest power increment in the hornblende spectrum.

Similarly, the 42 ± 3 Ma plateau age recorded in biotite from sample CS30-98 may be related to reheating associated with a slightly older tectonomagmatic event represented by a syntectonic granodiorite at Puerto Angel, which has yielded a 40 ± 2 Ma concordant U–Pb zircon age (Robinson, 1990). Subsequently, cooling through ~310–270° C by ~36 Ma (late Eocene) is indicated by the K-feldspar age. The buried Mesozoic top of the southern Oaxacan Complex was exposed by Miocene times because volcanic rocks as old as 17.5 Ma overlie the southern part of the Oaxacan Complex (Morán-Zenteno *et al.*, 1999).

If the late Eocene deformed pluton and cooling ages in the Xolapa and Oaxacan complexes east of Puerto Angel are related to arc magmatism, then they predate the inferred switch in the southern Mexican boundary from a transform to a trench (Schaaf *et al.*, 1995), suggesting that either the estimates of passage of the triple point are incorrect, or that an alternative model applies (*e.g.*, Keppie and Morán-Zenteno, 2003). On the other hand, the Oligocene–early Miocene coincides with northward migration of the arc from the southern coast of Mexico to the Trans-Mexican Volcanic Belt (Ferrari *et al.*, 1999). Such inland migration is consistent with both flattening of the subduction zone (Pardo and Suárez, 1995), and subduction erosion (Morán-Zenteno *et al.*, 1996).

CONCLUSIONS

The ~42 Ma biotite and ~36 Ma K-feldspar ages recorded in the southern Oaxacan Complex indicate rapid

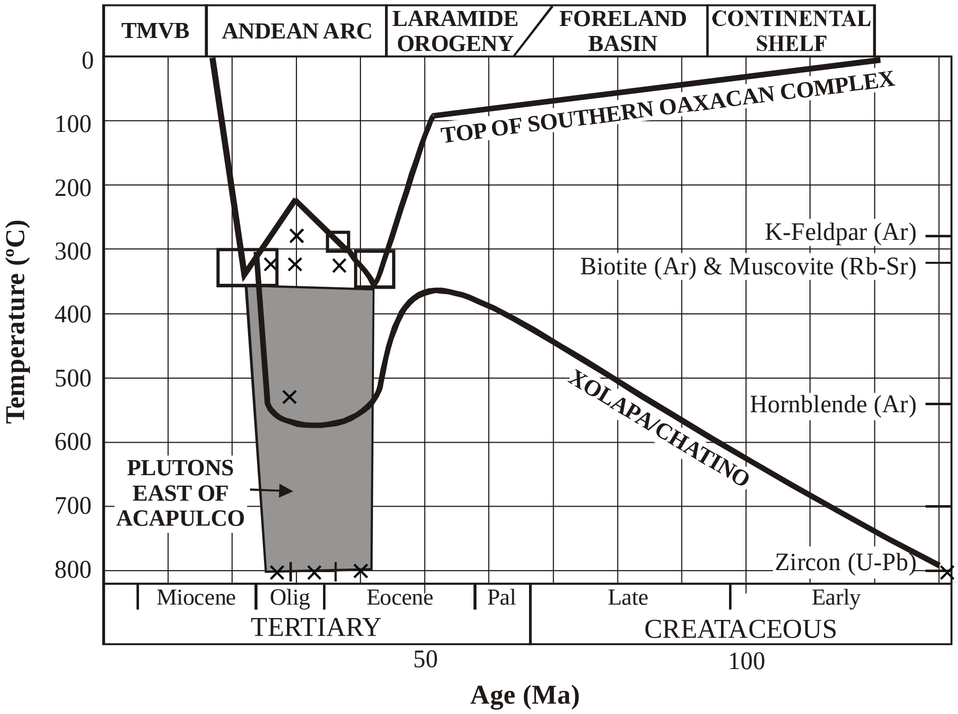

Figure 4. Time versus temperature diagram for the southern Oaxacan Complex and adjacent Xolapa Complex, Chatino Terrane (crosses indicate data from Herrmann *et al.*, 1994; Schaaf *et al.*, 1995; Ferrari *et al.*, 1999; Morán-Zenteno *et al.*, 1999; whereas boxes show error limits for data presented herein). The graph for the southern Oaxacan Complex (this study) shows the maximum reheating bracketed between 500° C and 280° C, the blocking temperatures of argon in hornblende and biotite, respectively. The graph for the Xolapa Complex shows the potential cooling curve from 800° C (the blocking temperature for U and Pb in zircon; Heaman and Parrish, 1991) with reheating due to intrusion of plutons between 40 and 27 Ma.

cooling following reheating associated with arc plutonism. As this occurred before the inferred passage of the Cocos–Caribbean–North America triple point, it is incompatible with the model where the Chortis block is placed adjacent to southern Mexico in the Eocene (*e.g.*, Ross and Scotese, 1988; Schaaf *et al.*, 1995). On the other hand, such late Eocene arc plutonism and cooling ages are consistent with a model involving inland migration of the arc, which is consistent with flattening of the subduction zone and subduction erosion (Morán-Zenteno *et al.*, 1996). The latter effects are required by the palinspastic model proposed by Keppie and Morán-Zenteno (2003) where the Chortis block is placed SSW of its present position.

Similarly, the ~24 Ma biotite cooling age from the southern Oaxacan Complex is inferred to be a consequence of reheating associated with intrusion of 35–25 Ma plutons in the adjacent Xolapa Complex. On the other hand, the ~584 Ma hornblende age is inferred to date resetting during the late Neoproterozoic, possibly correlative with Brasiliano tectonothermal events in South America.

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