El siguiente artículo fue publicado en Geologica Acta, Vol.5, Nº 2, 2007, 167-175, y lo puede consultar en http://dx.doi.org/10.1344/105.000000302

Geologica Acta, Vol.5, Nº 2, 2007, 167-175
Available online at www.geologica-acta.com

Is there a Grenvillian basement in the Guerrero-Morelos Platform of Mexico?

G. LEVRESSE [1] **J. TRITLLA** [1] **E. DELOULE** [2] **and P. PINTO-LINARES** [3]

[1] **Programa de Geofluidos, Centro de Geociencias, UNAM**
Campus Juriquilla, Carr. Qro-SLP km 15, Querétaro, México CP 76230, México. Levresse E-mail: glevresse@geociencias.unam.mx

[2] **CRPG-CNRS UPR A2300**
BP 20, 54501 Vandoeuvre-lès-Nancy Cédex, France

[3] **IPICYT, Dept. Geología Económica**
San Luis Potosí, S.L.P. México

ABSTRACT

In the Guerrero-Morelos platform (Guerrero State, Mexico) the adakitic rocks of Early Tertiary age contain abundant hornblende-rich tonalite xenoliths. Zircon crystals have been concentrated from both adakites and xenoliths, and dated using in-situ U-Pb ion microprobe analyses. These analyses indicate the presence of inherited Grenvillian and early Triassic/late Permian crust ages, as well as a Paleocene age related with the adakite rock intrusion. This range of inherited ages is reported for the first time in the Guerrero-Morelos platform, suggesting that a continous Grenvillian crust exists between the Oaxacan complex,to the East, and the Guerrero-Morelos platform.

KEYWORDS | U-Pb dating. Zircon. Guerrero. Grenvillian Age.

INTRODUCTION

The Sierra Madre del Sur (SMS) is an orogen thought to be formed through the accretion of several arc-related terranes (Guerrero, Mixteco, Zapoteco, Xolapa and Cuicateco; Campa and Coney, 1983; Fig. 1), each of whom seem to present a specific paleotectonic evolution. The Guerrero-Morelos platform is a part of the sedimentary cover of the Guerrero terrane that has been intruded by tertiary magmatic bodies.

Previous SMS geodynamic reconstructions were mainly based on the accurate description of the litho-structural units as well as the nature and mutual relationships between the intrusives and the deformation patterns (Campa and Coney, 1983). During the last 10 years a series of studies coupling absolute dating with isotope systematics allowed the reinterpretation of the paleotectonic settings and the geodynamic evolution of the western part of Mexico. Also, a wide calc-alkaline magmatic province has also been defined in the SMS (Morán-Zenteno et al., 1999), with ages ranging from early Paleocene to Miocene. These authors also suggested that the SMS volcanism took place after the Laramide Orogeny (post-collision) in a fast, convergent regime characterized by the subduction of oceanic crust underneath a thick continental crust.

An important key to decipher the geodynamic evolution of the western SMS is to ascertain the age of the basement and its relationship with the subsequent magmatism. Unfortunately, most of the age techniques based upon isotopic determinations, such as Rb-Sr or K-Ar, do not necessarily yield crystallization ages (Ortega-Gutiérrez, 1980; De Cserna and Fries, 1981; Linares and Urrutia-Fucugauchi, 1981; Bellon et al., 1982; Herwig, 1982; Hernández-Treviño et al., 1996; Correa-Mora, 1997; Alba-Aldave et al., 1998; Ortega-Gutiérrez et al., 1999). Moreover, the abundance of xenolithic material precludes the use of conventional dating methods, as only mixed ages can be obtained. Recently, U-Pb studies using the isotopic dilution method applied on multigrain fraction of zircons in the Guerrero terrane yielded discordant ages, suggesting an unclear possible heritage (Herrmann et al., 1994; Schaaf et al., 1995; Elías-Herrera et al., 2000).

Lately, Levresse et al. (2004) used the ion probe zircon U-Pb technique just to discern the age of the Mezcala adakite stock emplacement and skarn formation, without discussing the possible meaning of the inherited ages. So, the main goal of this paper is to interpret and place the zircon rim and core inherited ages found in the Mezcala adakite stock within the geological and geodynamical scenario of the Guerrero terrane in order to discern the possible presence of a Grenvillian and pre-Upper Jurassic basement underneath the Guerrero-Morelos platform.

THE SOUTHWESTERN MEXICO TERRANE ARCHITECTURE

The Guerrero terrane is thought to be formed by the accretion of island-arc sequences, mostly of Early Cretaceous and Late Jurassic ages (Centeno-GarcÌa et al., 1993). Both the stratigraphic relationships among these arc sequences as well as the nature and age of their basement are not yet clear (Campa and Coney, 1983). Campa

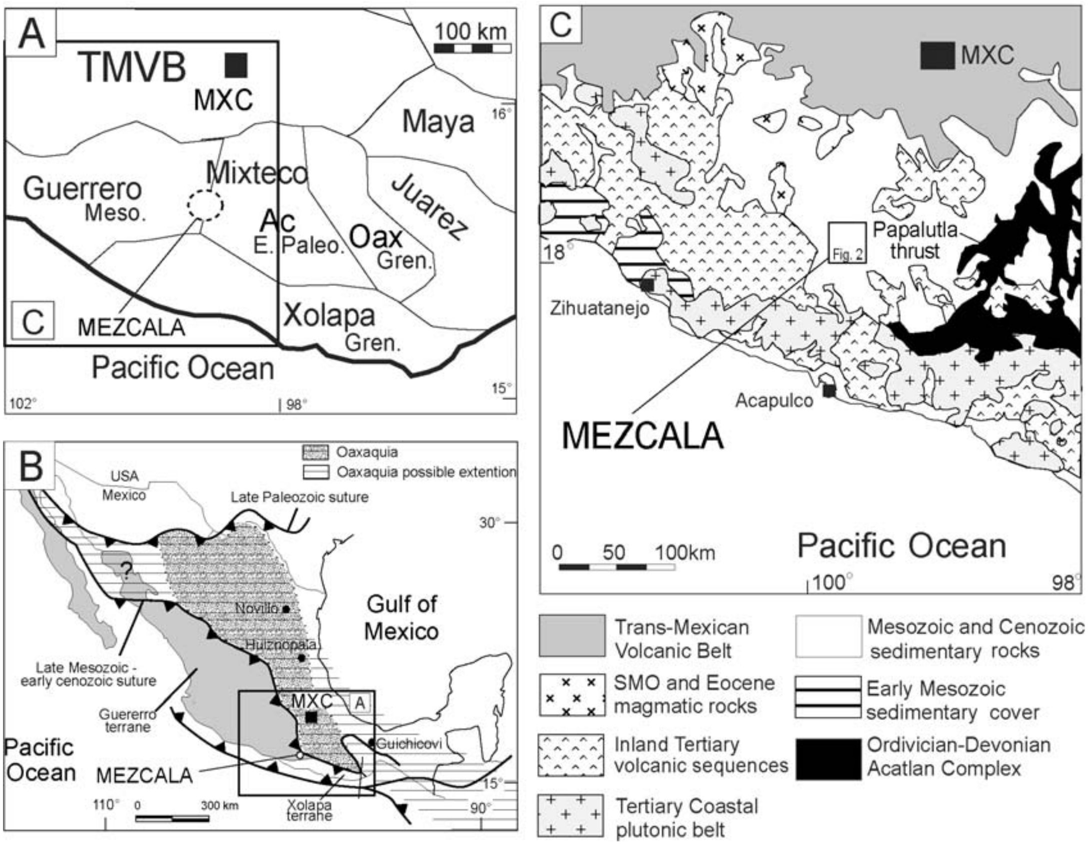

FIGURE 1 **A) Tectonostratigrafic division of southern Mexico and location of Mezcala district (modified from Campa and Coney, 1983). Ac: Acatlán complex; Oax: Oaxacan complex; Gren: Grenvillian; Meso: Mesozoic; E. Paleo: Early Paleozoic; TMVB: Trans Mexican volcanic belt; MXC: Mexico city. B) Tectonostratigrafy of southern Mexico (modified from Keppie et al., 2003) and the relationship between the Guerrero terrane and the Oaxaquian Grenvillian formations (Novillo gneiss, Huiznopala gneiss, Guichico complex, Oaxacan complex) including the Ordovician-Devonian Acatl·n complex. C) Map of southern Mexico showing the study area (modified from Ortega-Gutiérrez et al., 1999); MXC: Mexico City.**

and Coney (1983) proposed the inclusion of the Guerrero-Morelos platform into the Guerrero terrane, locating the terrane boundary at the west side of the platform. Sedlock et al. (1993) proposed the boundary to be located between the Mixteco and the Nahualt terranes, east of the study area. Some evidences indicate that the sedimentary sequences attributed to the Guerrero terrane, outcropping northwest of Acapulco, unconformably overlie a pre-Cretaceous rock assemblage of oceanic affinity (Centeno-García et al., 1993). The materials outcropping in the thrusts overlying continental crust, located in the easternmost sector, are probably related with the basement of the Mixteco terrane, which includes the Acatlán Complex (Campa and Coney, 1983).

The Acatlán Complex (Fig. 1) is a pre-Mississippian tectonically heterogeneous assemblage, mostly with an oceanic basin affinity, affected by metamorphism (greenschist to eclogite facies) combined to form a poly-deformed and metamorphosed basement unit (Fig. 1; Yáñez et al., 1991; Campa and López, 2000). The rocks of the metamorphic basement are interpreted to represent an early to middle Paleozoic suture after the collision of oceanic and continental crusts (Proenza et al., 2004).

The Acatlán Complex roots, of Grenvillian age, were identified indirectly in several locations by interpreting U-Pb discordia ages (Esperanza Granitoid, Ortega-Gutiérrez et al., 1999; Magdalena Migmatite and Tultitlan gabbro, Keppie et al., 2004). The Acatlán Complex is unconformably overlain by a deformed volcano-sedimentary sequence attributed to a volcanic arc of presumed Mississippian to Permian ages (Navarro-Santillan et al., 2002). Ignimbrites and andesites of apparent Triassic age, epicontinental and marine sediments of Middle Jurassic and Cretaceous ages, and Cenozoic continental clastic and volcanic rocks complete the stratigrafic column (Morán-Zenteno et al., 1999).

The available information on the deep structure and lateral changes of the lower crust in southern Mexico is, so far, scarce. Ortega-Guitiérrez (1993) proposed that the general arrangement and tectonic history portrayed by the exposed basement units suggest that fragments of continental crust, gradually younger, were aggregated around the Oaxacan Complex during Paleozoic and Mesozoic times. The Oaxacan Complex (Grenvillian), a granulite-facies complex with associated mafic and felsic orthogneisses, paragneisses, meta-anorthosites and charnockites, presents two tectonothermal events at ca. 1100Ma and ca. 990Ma (Solari et al., 2003). The post-metamorphic cover includes sedimentary sequences of Tremadoc, Mississippian–Permian and Jurassic–Cretaceous ages (Schlaepfer, 1970). Recent geochronological studies (Ducea et al., 2004) suggest the existence of a common Grenvillian basement for the Xolapa and Oaxaca terranes. In addition, the Xolapa, Mixteco and Oaxaca terranes have Gondwanan geochemical affinities (Dickinson and Lawton, 2001).

THE GUERRERO-MORELOS PLATFORM GEOLOGICAL SETTINGS

The Guerrero terrane is unconformably covered by a more than 2000 m thick sequence of carbonate rocks that consists of moderately to strongly folded Mesozoic limestone and clastic units of the Morelos, Cuautla and Mezcala Formations (Fms) (Fries, 1960).

The Albian-Cenomanian Morelos Fm is made up by an alternance of gray limestones and dolostone beds, with some flint nodule rich horizons and silicified fossil fragments. Locally, a pure anhydrite member is located at the base of this formation (Fries, 1960). The Morelos Fm is conformably overlain by the Cuautla Fm of Turonian age, which consists of an alternance of calcareous shales and limestones. The upper Cretaceous Mezcala Fm (Coniacian to Campanian age) conformably overlains the Cuautla Fm and consists of calcareous shales, and bedded sandstones. The sedimentary sequence was deformed by the Laramide Orogeny.

Late Cretaceous to Early Tertiary plutons of adakite affinity and younger mid-Tertiary dacite plugs intrude the carbonate sequence. Locally, these intrusives developed Fe-rich skarn bodies, including some with associated gold mineralization.

N-S and WNW-ESE structural trends control the distribution of the granodioritic stocks (De la Garza et al., 1996), which intruded the whole sedimentary sequence (Fig. 2). Meza-Figueroa et al. (2003) determined the Laramide age (64±1 Ma; ^{40}Ar/^{39}Ar on biotite) for the calc-alkaline granodiorites; these intrusive rocks were reclassified as adakites by Gonzalez-Partida et al. (2003).

Mid to late Tertiary volcanic rocks of the Sierra Madre Occidental province, including rhyolite, trachyte and minor andesite, unconformably cover the Mesozoic series.

Adakite petrography

The adakites always present a porphyritic texture, with phenocrists composed by plagio-clase (oligoclase-andesine; 50-60%), microcline (7-15%), quartz (20-30%), biotite (15-20%), and magnesio-hornblende (5-10%), and a groundmass composed mainly by microcrystalline quartz and plagioclase (Fig. 2, Table 1). Minor phases include apatite, titanite, zircon, hematite and titanomag-

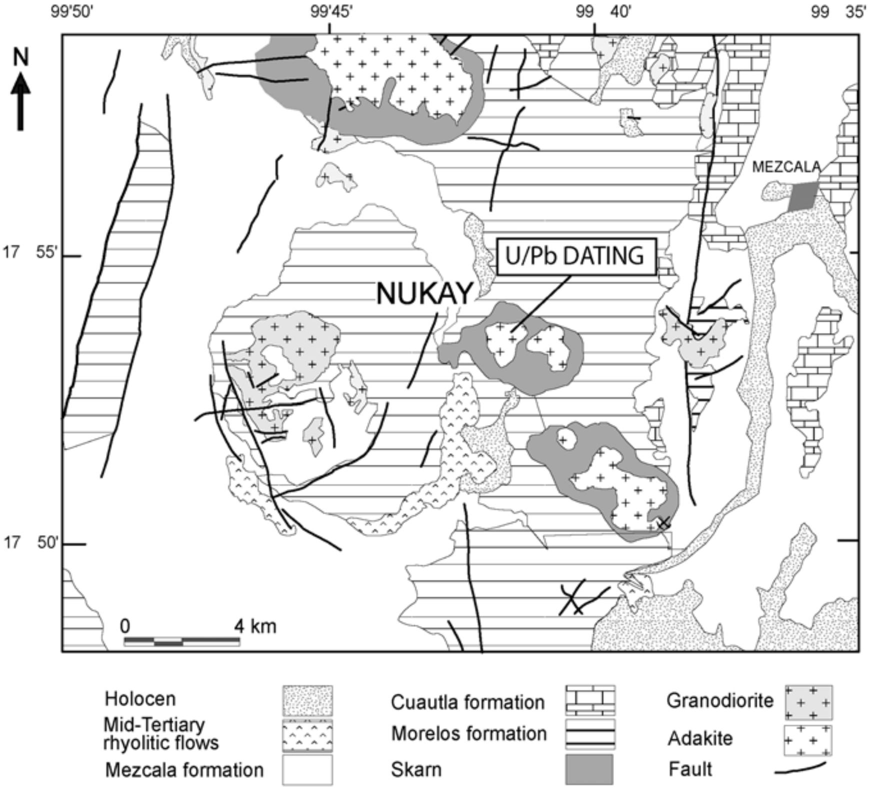

FIGURE 2 | **Geological map of the Nukay adakitic pluton area in the Mezcala mineral district.**

netite. This rock is lately altered by a low temperature propillitic event.

These intrusives are characterized by the high abundande of tonalitic xenoliths, mainly composed by hornblende (60-70%), plagioclase (15-20%), rare interstitial orthoclase, abundant apatite (15-20%), and biotite (5-10%). These xenoliths are always affected by the hydrothermal alteration event that produced a pervasive albitization of the plagioclase, with local sericitization, and the subsequent formation of epidote after Ca release during the albitization process. Primary ferromagnesian minerals (hornblende, biotite) and apatite remain almost undisturbed by this alteration phenomenon, suggesting that the fluid involved was a high temperature, Fe-K-rich magmatic fluid. The presence of these tonalitic xenoliths provides the possibility of sampling parts of the Guerrero-Morelos platform basement (lower crust?).

ION PROBE ZIRCON U-PB GEOCHRONOLOGY

Sample selection

Fifty Kg of rock sample from the Nukay stock were collected for zircon separation. Samples were powdered and sieved using 200-50 μm sieves. Mineral fractions were obtained by density preconcentration with the use of heavy liquids. The non magnetic fraction was separated with a Cook isodynamic magnet. Final zircon fractions, suitable for analysis, were hand picked under a binocular microscope and cold mounted in an epoxy resin with a zircon standard (91500, Wiedenbeck et al., 1995), polished and gold-coated. All grains were examined using a SEM in back-scattering mode in order to characterize their internal structure. The selected grains present well-preserved prismatic shapes and euhedral growth zones (Fig. 3), indicative of their magmatic origin (Pupin, 1983), and are devoid of any significant subsequent resorption and/or recrystallization.

Analytical techniques

Zircon U-Pb analyses were performed on a Cameca IMS-1270 ion microprobe at the CRPG-CNRS, Nancy, France (Deloule et al., 2002). The instrument was used in monocollection ion counting mode, and the measurements were made by peak jumping. An empirical linear correlation (Compston et al., 1992) was defined between UO^+/U^+ and Pb^+/U^+ from the standard measurements to determine the relative sensitivity factor for Pb and U. Correction for common lead was made by measuring the ^{204}Pb amount and using the Stacey and Kramers (1975)

TABLE 1 **U/Pb isotopic data for single zircon crystal from Nukay adakite obtained by ion microprobe analysis (CAMECA IMS 1270).**

LABEL	MEASURED DATA					CONTENT (in ppm)			CONCORDIA INVERSE					CONCORDIA					APPARENT AGES U-Pb			
	Is ^{206}Pb	^{207}Pb / ^{206}Pb	^{204}Pb / ^{206}Pb	^{206}Pb / ^{238}U	UO / U	Pb	U	Th	Th/U	^{238}U / ^{206}Pb	±	^{207}Pb / ^{206}Pb	±	^{207}Pb / ^{235}U	error	^{206}Pb / ^{238}U	error	Correl.err	^{206}Pb / ^{238}U	error	^{207}Pb / ^{235}U	error
mx1	1928	0.04921	0.00047	0.022	7.73	0.8	99.4	47.3	0.5	109.26	1.92	0.049	0.000	0.060	0.001	0.009	0.000	0.770	59	2	60	2
mx4	3323	0.04906	0.00010	0.024	7.01	6.4	775.8	232.2	0.3	104.92	1.00	0.049	0.000	0.063	0.001	0.010	0.000	0.783	61	2	62	2
mx2	2248	0.04780	0.00013	0.024	7.01	3.1	377.8	112.8	0.3	104.18	1.17	0.048	0.000	0.061	0.001	0.010	0.000	0.941	62	2	60	2
mx17	1691	0.04844	0.00038	0.014	6.15	0.5	55.8	22.5	0.4	103.22	2.05	0.048	0.001	0.066	0.002	0.010	0.000	0.766	62	2	65	4
mx15	1272	0.04890	0.00057	0.015	6.30	0.4	45.8	13.7	0.3	103.08	2.53	0.049	0.000	0.066	0.002	0.010	0.000	0.696	62	4	64	4
mx13	1375	0.04732	0.00034	0.018	6.72	0.5	64.1	25.4	0.4	101.32	1.94	0.047	0.000	0.068	0.002	0.010	0.000	0.811	63	2	67	4
mx12	2659	0.04821	0.00010	0.025	7.01	4.6	526.3	213.1	0.4	97.95	0.95	0.048	0.000	0.066	0.001	0.010	0.000	0.792	65	2	65	2
mx6	2206	0.04711	0.00021	0.027	8.10	1.9	211.9	84.4	0.4	96.75	1.60	0.047	0.000	0.070	0.001	0.010	0.000	0.811	66	2	68	2
mx19	10320	0.04872	0.00003	0.056	7.37	15.1	826.3	472.5	0.6	47.13	0.44	0.049	0.000	0.142	0.001	0.021	0.000	0.911	135	2	134	2
mx18	9460	0.04892	0.00003	0.056	7.32	15.1	821.4	457.2	0.6	46.73	0.44	0.049	0.000	0.143	0.001	0.021	0.000	0.894	136	2	136	2
mx16	2251	0.05195	0.00035	0.046	5.68	0.8	24.6	10.6	0.4	26.15	1.39	0.052	0.000	0.272	0.015	0.038	0.002	0.957	242	23	244	24
mx20	7440	0.07316	0.00003	0.427	7.20	10.4	72.9	33.0	0.5	6.02	0.06	0.073	0.000	1.668	0.016	0.166	0.002	0.968	990	16	996	12
mx11	20096	0.07845	0.00003	0.338	6.90	6.7	44.9	13.5	0.3	5.73	0.21	0.078	0.000	1.893	0.070	0.175	0.006	0.999	1037	70	1078	48
mx5	15202	0.07808	0.00010	0.508	8.43	4.7	30.7	10.0	0.3	5.61	0.10	0.078	0.000	1.900	0.033	0.178	0.003	0.983	1057	34	1081	24
mx10	840	0.04885	0.00040	0.027	7.96	0.5	61.2	40.4	0.7	96.03	1.97	0.049	0.000	0.080	0.003	0.010	0.000	0.656	67	2	78	4
mx3	1325	0.04883	0.00019	0.031	8.49	0.9	98.6	47.6	0.5	92.32	1.47	0.049	0.000	0.081	0.002	0.011	0.000	0.755	69	2	79	4
mx9	779	0.04910	0.00044	0.033	8.67	0.6	59.4	19.3	0.3	89.37	1.60	0.049	0.000	0.087	0.002	0.011	0.000	0.666	72	2	85	4
mx7	390	0.05120	0.00027	0.031	8.27	0.3	27.5	7.2	0.3	85.89	1.56	0.051	0.000	0.119	0.003	0.012	0.000	0.650	75	2	114	6
mx24	3893	0.05643	0.00011	0.084	7.52	6.5	246.8	52.4	0.2	32.50	1.37	0.056	0.000	0.233	0.010	0.031	0.001	0.983	195	16	213	16
mx22	10892	0.07196	0.00003	0.177	7.13	18.7	312.5	126.8	0.4	14.35	0.76	0.072	0.000	0.689	0.037	0.070	0.004	0.998	434	44	532	44
mx23	9111	0.06320	0.00010	0.254	8.11	20.2	282.9	84.2	0.3	12.00	0.15	0.063	0.000	0.710	0.010	0.083	0.001	0.915	516	12	545	12

model for terrestrial lead isotopic composition. The ^{206}Pb/^{204}Pb ratios were always higher than 1,000, indicating relatively low ^{204}Pb amount.

Isotopic data with their analytical uncertainties and calculated ages are listed in Table 1 (Levresse et al., 2004). All the ages were calculated using the Isoplot program (Ludwig, 2000) and the weighted mean at 95% confidence levels. More details on the analytical techniques can be found in Levresse et al. (2004).

Results

The twenty-one ^{206}Pb/^{238}Pb ages obtained scatter between 59±1Ma and 1057±17Ma (Fig. 4). Fifteen ^{206}Pb/^{238}U and ^{207}Pb/^{235}U ages are concordant or sub-concordant and seven are discordant. The higher intrinsic error on ^{206}Pb/^{238}U vs. ^{207}Pb/^{235}U values yield elliptical-shaped representative points in the concordia diagram (Fig. 4). The ^{207}Pb/^{235}U ages are very sensitive to a common lead contribution because the signal of the ^{207}Pb ion is about ten times lower than the ^{206}Pb ion signal. Additionally, the ^{207}Pb, product of the ^{235}U disintegration, presents a very low concentration in young zircon grains. Therefore, the individual ^{206}Pb/^{238}U ages are more reliable.

Ion-probe data on selected zircons define a geochronologically homogeneous group consisting of eight concordant analyses taking into account the youngest ages (Fig. 4). These yield a weighted mean age of Early Paleocene (63±2Ma), that was interpreted by Levresse et al. (2004) as the emplacement age of the adakite and skarn formation.

Six other concordant ages reveal the existence of three older magmatic events located at Early Cretaceous (ca. 135 Ma, n=2), Triassic (ca. 240 Ma, n=1) and Grenvillian (ca. 1000 Ma, n=3) ages.

Seven discordant ages, ranging from 67±1Ma to 516±12Ma, represent mixing-ages of the inherited cores from plutonic rocks probably belonging to Guerrero-Morelos platform basement. Five of them are distributed along a discordia line, where the lower intercept is well defined by the youngest group age (ca. 63 Ma), whereas the upper intercept plot into the Grenvillian age range (between 1,000 Ma and 1,150Ma).

It is noteworthy that the age distribution of the zircons does not correlate with an specific position

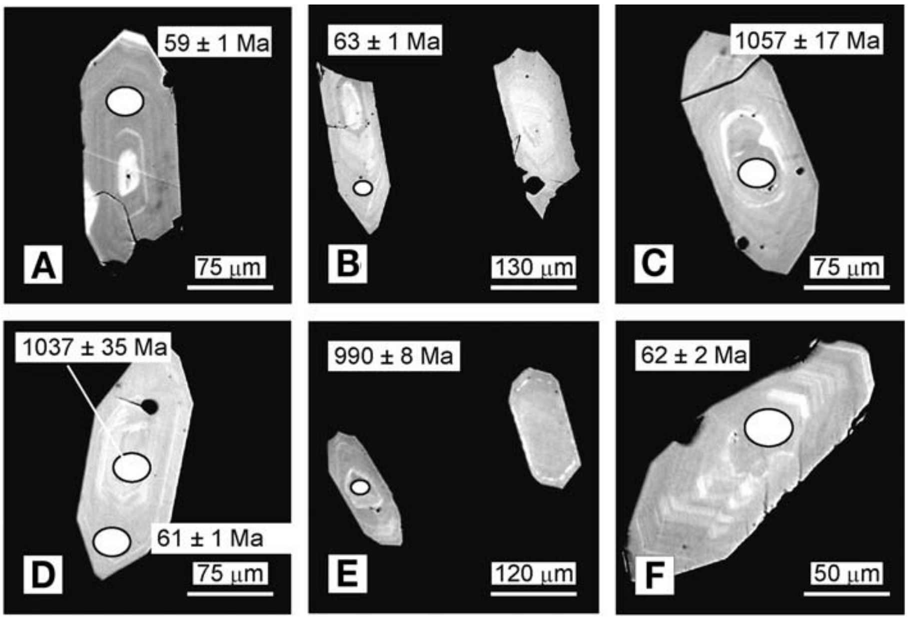

FIGURE 3 **BSE images for some of the dated zircon from the Nukay adakitic pluton. The elliptic holes on the grains represent the analyzed spot positions. The $^{238}U/^{206}Pb$ age are also indicated.**

(core, rims) of the analysis within a single crystal: while some zircon crystals present single Grenvillian, Paleozoic or Tertiary ages, some others present an old (Grenvillian or Paleozoic) inherited core and younger (Paleozoic, Tertiary) outer rims.

GEOLOGICAL SIGNIFICANCE OF THE INHERITED MEZCALA AGES

The eight concordant younger ages found during this zircon study were already interpreted in Levresse et al. (2004) exclusively to place the Mezcala gold-bearing skarn deposits into the Lower Tertiary geological scenario. The rest of gathered data were disregarded in that study as they are not related with the Mezcala mineralizing events, the main focus of the 2004 paper.

The inherited component of the Nukay zircons contain the most complete history found on the magmatic events that affected the basement rocks of the Guerrero-Morelos platform. These newly uncovered magmatic events can be crucial to understand the origin and evolution of the Guerrero and associated terranes in SW Mexico.

The Grenvillian inherited ages clearly indicate the existence of a Precambrian basement underneath the Guerrero-Morelos platform and, in extension, underneath the Guerrero Terrane. The existence of this basement has important implications on the geodynamic history of the SMS. Three different possibilities can be considered: 1) the presence of a thrust of the Guerrero Terrane over an Oaxaquian crust of Grenvillian age, located East of the Guerrero terrane, that does not outcrop; 2) a supposed thrust of the Guerrero terrane over a crust of Grenvillian age from the Mixteco terrane (in agreement with Campa and Coney, 1983 ; in opposition with Sedlock et al., 1993), and 3) the existence of an *in situ* Grenvillian crust underlying the so-called Guerrero terrane. This last proposition is strongly supported by previous U-Pb zircon dating studies carried out by Elías-Herrera et al. (2000) on the Tizapa metagranite northwest of the Mezcala area. These authors also identified the presence of an old continental crust (ca. 1,000 Ma) beneath at least the eastern part of the Guerrero terrane, which can now be extended south-eastward to the Mezcala area.

The presence of an Early Cretaceous thermal episode suggests a link between the magmatic history of the Mezcala basement with the Guerrero terrane (Hermann et al., 1994; Elías-Herrera and Ortega-Gutiérrez, 2002; Keppie et al., 2003). Similar U-Pb ages on zircons were reported by Robinson et al. (1989) and Hermann et al. (1994), even though the latter considered the pre-Cenozoic ages as speculative. Evidences for an Early Triassic-Late Permian magmatic episode for the Guerrero terrane are rarely reported, but they have been already found in the Acatlán (Mixteco Terrane; Yáñez et al., 1991; Elías-Herrera and Ortega-Gutiérrez, 2002) and the Juchatengo complex (Grajales-Nishimura et al., 1999) of the Xolapa terrane.

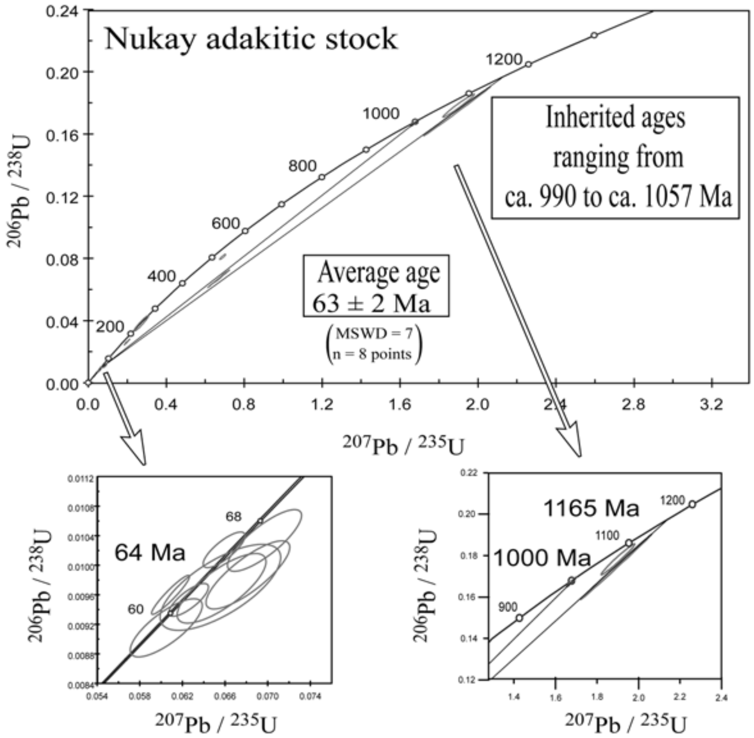

FIGURE 4 | **Adakite. ^{206}Pb/^{238}U versus ^{207}Pb/^{235}U plot from ion microprobe analyses of zircon. Ages are calculated with the Isoplot program (Ludwig, 2000). Errors are given in 1. See text for further discussion.**

CONCLUSIONS

The new data on inherited ages in zircons we present in this paper confirm the existence of three major magmatic pulses from Grenvillian to early Tertiary times in the Guerrero Terrane.

Moreover, the uncovering of a Grenvilian magmatic episode implies the existence of a Grenvillian crust at this location. Whether this crust represents an *in situ* basement or the sedimentary cover thrusted over this Grenvillian crust will be a matter of debate. In any case, these new uncovered ages imply the necessity to re-open the discussion of the tectonic evolution and the crustal structure of southern Mexico.

ACKNOWLEDGEMENTS

We wish to thank the Peñoles Mining Corporation for their logistic field assistance and the permission to publish the results. The ion-probe analyses were performed under the supervision of Dr. E. Deloule, Dr. M. Champenois and D. Mangin at the CRPG-CNRS, Nancy, France. We also wish to thank Dr Vaquer and an anonymous reviewer for their useful comments.

REFERENCES

Alba-Aldave, L., Hernández-Bernal, S., Morán-Zenteno, D.J., Angeles-García, S., 1998. Edades Rb/Sr de rocas plutónicas del Estado de Guerrero, México. Primera Reunión Nacional de Ciencias de la Tierra, México, D. F., Abstracts with Programs, p. 145.

Bellon, H., Maury, R.C., Stephan, J.F., 1982. Dioritic basement, site 493: Petrology, geochemistry, and geodynamics. Initial Reports of the Deep Sea Drilling Project, LXVI, National Science Foundation, National Ocean Sediment Coring Program, 66, 723-730.

Campa, M.F., Coney, P.J., 1983. Tectono-stratigraphic terranes and mineral resource distributions in Mexico. Canadian Journal of Earth Sciences, 20, 1040-1051.

Campa, M.F., Lopez, M., 2000. Lavas máficas del Pérmico en el terreno Mixteco. Simposio regional sobre el sur de México, Puerto Vallarta, Unión Geofísica Mexicana, GEOS, Proceedings, p. 329.

Centeno-García, E., Ruiz, J., Coney, P.J., Patchett, P.J., Ortega-Gutiérrez, F., 1993. Guerrero terrane of Mexico: Its role in the Southern Cordillera from new geochemical data. Geology, 21, 419-422.

Compston, W., Williams, I., Kirschvink, J.L., Zichao, Z., Guogan, M., 1992. Zircon U/Pb ages for the Early Cambrian time scale. Journal of Geological Society, London, 149, 171-184.

Correa-Mora, F., 1997. Estudio petrológico y geoquímico del complejo intrusivo de Xaltianguis, Guerrero, México. Undergraduate Thesis. Universidad Nacional Autónoma de México, 44 pp. Unpublished.

De Cserna, Z., Fries, C., 1981. Carta Geológica de México. Hoja Taxco 14Q-h(7), Geología de los Estados de Guerrero, México y Morelos. Scale 1:100,000, Universidad Nacional Autónoma de México. México, Instituto de Geología, 47 pp., 1 fold. map.

De la Garza, V., Téllez, R., Díaz, R., Hernández, A., 1996. Geology of the Bermejal iron-gold deposit Mezcala, Guerrero, México. In: Coyner, A.R., Fahey, P.L. (eds.). Geology and Ore Deposits of the American Cordillera, Nevada. Reno/Sparks, Geological Society of Nevada Symposium (April 1995), Proceedings, 111, 1354-1368.

Deloule, E., Alexandrov, P., Cheilletz, A., Laumonier, P., Barbey, P., 2002. In-situ U-Pb zircon ages for Early Ordovician magmatism in the eastern Pyrenees, France: the Canigou orthogneisses. International Journal of Earth Sciences, 91, 398-405.

Dickinson, W.R., Lawton, T., 2001. Geotectonic assembly and fragmentation of Mexico. Geological Society of America Bulletin, 113, 1142-1160.

Ducea, M.N., Gehrels, G.E., Shoemaker, S., Ruiz, J., Valencia, V.A., 2004. Geologic evolution of the Xolapa Complex, southern Mexico: Evidence from U-Pb zircon geochronology. Geological Society of America Bulletin, 116(7/8), 1016-1025.

Elías-Herrera, M., Ortega-Gutiérrez, F., 2002. Caltepec fault zone: An early Permian dextral transpressional boundary between the Proterozoic axacan and Paleozoic Acatlan complexes, southern Mexico and regional tectonic implications. Tectonics, 21, 220-234.

Elías-Herrera, M., Sánchez-Zavala, J.L., Macias-Romo, C., 2000. Geologic and geochronologic data from the Guerrero Terrane in the Tejupilco area, southern Mexico: new contrains on its tectonic interpretation. Journal of South America Earth Sciences, 13, 355-375.

Fries, C., Jr., 1960. Geología del Estado de Morelos y de partes adyacentes de México y Guerrero, región central meridional de México. Instituto de Geología, Boletín, 60, 236 pp.

González-Partida E, Levresse, G., Cheilletz, A,, Gasquet, D,, Jones, D,, 2003. Paleocene Adakite bearing Au-Fe intrusive rocks, Mezcala, Mexico: Evidence from geochemical characteristics. Journal of Geochemical Exploration, 410(5), 1-16.

Grajales-Nishimura, J.M., Centeno-García, E., Keppie, J.D., Dostal, J., 1999. Geochemistry of Paleozoic basalts from the Juchatengo complex of souterhn Mexico: tectonic implications. Journal of South American Earth Sciences, 12, 537-544.

Herrmann, U.R., Nelson, B.K., Ratschbacher, L., 1994. The origin of a terrane: U /Pb zircon geochronology and tectonic evolution of the Xolapa complex (southern Mexico). Tectonics, 13, 455-474.

Hernández-Treviño, T., Cabral-Cano, E., Morán-Zenteno, D., Schaaf, P., 1996. Geoquímica y geocronología de las rocas magmáticas de la región de Tierra Colorada-Sierra de Alquitrán, Estado de Guerrero, y su significado tectónico. Annual meeting, Puerto Vallarta, Union Geofísica Mexicana, Abstracts with Programs, GEOS, 203–204.

Herwig, J.C., 1982. Stratigraphy, structure and massive sulfide potential of Late Mesozoic Metamorphic rocks near El Cirian, Mexico State, Mexico. Doctoral thesis. University of Texas at Austin, 107 pp.

Keppie, J.D., Dostal, J., Cameron, K.L., Solari, L.A., Ortega-Gutiérrez, F., López, R., 2003. Geochronology and geochemistry of Grenvillian igneous suites in the northern Oaxacan Complex, Southern Mexico: tectonic implication. Precambrian Research, 120, 365-389.

Keppie, J.D., Nance, R.D., Powell, J.T., Mumma, S.A., Dostal, J., Fox, D., Muise, J., Ortega-Rivera, A., Miller, B.V., Lee, J.W.K., 2004. Mid-Jurassic tectonothermal event superposed on a Paleozoic geological record in the Acatlán Complex of southern Mexico: hotspot activity during the breakup of Pangea. Gondwana Research, 7, 239-260.

Levresse, G., Gonzalez-Partida, E., Cheilletz, A., Gasquet, D., Deloule, E., Carillo-Chavez, A., Tritlla, J., Camprubi, A., 2004. Petrology, U/Pb dating and (C-O) stable isotope constraints on the source and evolution of the adakite-related Mezcala Fe-Au skarn district, Guerrero, Mexico. Mineralium Deposita, 39, 301-312.

Linares, E., Urrutia-Fucugauchi, J., 1981. K-Ar age of the Riolita Tilzapotla volcanic activity, Guerrero State, Mexico and its stratigraphic implications. Isochron/West, 32, 5-6.

Ludwig, K.R., 2000. Isoplot/Ex 2.0X. A Geochronological Toolkit for Microsoft Excel. Berkley Geochronology Center Special Publication, n.1a.

Meza-Figueroa, D., Valencia-Moreno, M., Valencia, V.A., Ochoa-Landin, L., Perez-Segura, E., Díaz-Salgado, C., 2003. Major trace element geochemistry and ^{40}Ar/^{39}Ar geochronology of Laramide plutonic rocks associated with gold –bearing Fe skarn deposits in Guerrero state, southern Mexico. Journal of South American Earth Sciences, 16, 205-217.

Morán-Zenteno, D.J., Tolson, G., Martínez-Serrano, R., Martiny, B., Schaff, P., Silva-Romo, G., Macías-Romo, C., Alba-Aldave, L., Hernández-Bernal, M.S., Solís-Pichardo, G.N., 1999. Tertiary arc-magmatism of the Sierra Madre del Sur, México, and its transition to the volcanic activity of the Trans-Mexican Volcanic Belt. Journal of South American Earth Sciences, 12, 513-535.

Navarro-Santillan, D., Sour-Tovar, F., Centeno-Garcia, E., 2002. Lower Mississippian (Osagean) brachiopods from the Santiago Fm, Oaxaca, Mexico: stratigraphic and tectonic implications. Journal of South American Earth Sciences, 15, 327-336.

Ortega-Gutiérrez, F., 1980. Rocas volcánicas del Maastrichtiano en el área de San Juan Tetelcingo, Estado de Guerrero. Libro guía de la excursión geológica a la parte cental de la Cuenca del alto Río Balsas, estados de Guerrero y Puebla. Sociedad Geológica Mexicana, 34-38.

Ortega-Gutiérrez, F., 1993. Tectonostratigraphic analysis and significance of the Paleozoic Acatlán Complex of Southern

Mexico. In: Ortega-Gutiérrez, F., Centeno-García, D., Morán-Zenteno, J., Gómez-Caballero, A. (eds.). Terrane geology of southern Mexico. First Circum-Pacific and Circum-Atlantic Terrane Conference, Guanajuato, Universidad Nacional Autónoma de México, Instituto de Geología, Guidebook of field trip B, 67-84.

Ortega-Gutiérrez, F., Elías-Herrera, M., Reyes-Salas, M., Macías-Romo, C., López, R., 1999. Late Ordovician–Early Silurian continental collision orogeny in southern Mexico and its bearing on Gondwana–Laurentia connections. Geology, 27, 719-722.

Proenza, J.A., Ortega-Gutiérrez, F., Camprubí, A., Tritlla, J., Elías-Herrera, M., Reyes-Salas, M., 2004. Paleozoic serpentinite-enclosed chromitites from Tehuitzingo (Acatlán Complex, southern Mexico): A petrological and mineralogical study. Journal of South American Earth Sciences, 16(8), 649-666.

Pupin, J.P., 1983, Typologie des zircons des termes saturés intermediaries et diferencies des series alkalines du Mont-Dore et de la Chain de Puys (Massif Central francais). Comptes Rendus de l'Académie des Sciences, 296, 761-764.

Robinson, K.L., Gastil, R.G., Campa, M.F., Rámirez-Espinosa, J., 1989. Geochronology of basement and metasedimentary rocks in southern Mexico and their relation to metasedimentary rocks in Peninsular California. Geological Society of America Programs with Abstracts, 21, 135.

Schaaf, P., Morán-Zenteno, D.J., Hernández-Bernal, M.S., Solís-Pichardo, G., Tolson, G., Köler, H., 1995. Paleogene continental margin truncation in southwestern Mexico: Geochronological evidence. Tectonics, 14, 1339–1350.

Schlaepfer, C.J., 1970. Geología terciaria del área de Yanhuitlán-Nochixtlán, Oaxaca. In: Segura, L.R., Rodríguez-Torres, R. (eds.). Libro-Guía de la Excursión México-Oaxaca, México, Sociedad Geológica Mexicana, 85-96.

Sedlock, R.L., Ortega-Gutiérrez, F., Speed, R.C., 1993. Tectonostratigraphic terranes and tectonic evolution of Mexico. Geological Society of America Special Paper, 278, p. 153.

Solari, L.A., Keppie, J.D., Ortega-Gutiérrez, F., Cameron, K.L., López, R., Hames, W.E., 2003. 990 and 1100 Ma Grenvillian tectonothermal events in the northen Oaxacan Complex, southern Mexico: roots of an orogen. Tectonophysics, 365, 257-282.

Stacey, J.S., Kramers, J.D., 1975, Approximation of terrestrial lead isotope evolution by a two-stage model. Earth and Planetary Sciences Letters, 26, 207-221.

Wiedenbeck, M., Allé, P., Corfu, F., Griffin, W.L., Meier, M., Oberli, F., Von Quadt, A., Roddick, J.C., Spiegel, W., 1995. Three natural zircon standards for U-Th-Pb, Lu-Hf, trace elements and REE analysis. Geostandard Newsletters, 19, 1-23.

Yáñez, P., Ruiz, J., Patchett, P.J., Ortega-Gutiérrez, F., Gehrels, G.E., 1991. Isotopic studies of the Acatlán Complex, southern Mexico: Implications for Paleozoic North American tectonics. Bulletin of the Geological Society of America, 103, 817-828.

**Manuscript received November 2005;
revision accepted October 2006.**