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Earliest Arikareean (later early Oligocene) Iniyoo local Fauna from Chilapa Formation of Santiago Yolomécatl area in northwestern Oaxaca, southern Mexico

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A B S T R A C T

Strata containing the Iniyoo Local Fauna (LF) crop out in the outskirts of Santiago Yolomécatl in the Yolomécatl Subbasin of the southeastern Tlaxiaco Basin in northwestern Oaxaca, southern Mexico. The assemblage is from a 325-m-thick fluviolacustrine unit previously assigned to the Yanhuitlán Formation and then the Yolomécatl Formation, which was restricted to the Yolomécatl Subbasin and its immediate vicinity. However, recent field investigations and laboratory analyses indicate the unit is, instead, a marginal facies of the dominantly lacustrine Chilapa Formation, which unconformably overlies the Yanhuitlán Formation where intervening volcanic units are absent. Consequently, Yolomécatl Formation is abandoned in favor of Chilapa Formation on the bases of synonymy and priority. Similarly, San Marcos Andesite and Nicananduta “Group” were applied to the same exposures of an andesitic unit interfingering with the Chilapa Formation. Accordingly, Nicananduta “Group” is abandoned and replaced by San Marcos Andesite for the same reasons.

The Iniyoo LF is earliest Arikareean (Ar1) (i.e., later early Oligocene) in age, not latest Uintan to late Chadronian (i.e., later early middle to latest Eocene), based on the first appearance datum for the amphicyonid *Mammacyon* and the last appearance datums of the tayassuid *Perchoerus probus* and the rhinocerotid *Subhyracodon*. That age assignment is supported by (1) corrected potassium-argon (K–Ar) dates of 28.939 ± 0.6 and 30.376 ± 0.6 Ma for the Yucudaac Andesite’s lowermost flow or lower tongue, which underlies the Chilapa Formation north of the Yolomécatl Subbasin, (2) a corrected ^{40}argon/^{39}argon (Ar/Ar) date of 27.829 ± 0.716 Ma for the correlative Nicananduta “Group” (= San Marcos Andesite), which overlies the Chilapa Formation in the Yolomécatl Subbasin, and (3) uranium-lead (U–Pb) maximum depositional ages of 30.6 ± 0.77 and 30.62 ± 0.67 Ma for detrital zircon grains from sandstone beds occurring above the bottom and top, respectively, of the nearly 88.4-m-thick vertebrate fossil-bearing interval. The K–Ar and Ar/Ar dates further constrain the age of the Iniyoo LF to an interval spanning about 27.83–28.94 Ma ago.

A corrected Ar/Ar date of 40.561 ± 1.009 Ma for potassium-feldspar crystals in a bed originally identified as a silicified tuff sheet and later determined during the current investigation to be a sandstone bed was bracketed by the two sandstone beds subjected to U–Pb dating analyses. However, the last Ar/Ar age is much too old when compared with the two U–Pb dates for the Chilapa Formation and the three K–Ar and Ar/Ar for volcanic units bracketing the formation. Presumably, the dated material represented volcanic debris reworked from a substantially older unit. Consequently, the Ar/Ar date and any land mammal age assignment based on it are considered highly unreliable.

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1. Introduction

A land mammal assemblage of Paleogene age, the Iniyoo Local Fauna (LF) of Jiménez-Hidalgo et al. (2015 [available online 2014], p. 40) (= Yolomécatl and Yanhuitlán LFs of Ferrusquía-Villafranca and Ruiz-González, 2015, p. 330, table 1, p. 326, formation 4a), along with the respective fossil localities and at least 20 fossil-bearing beds, occurs in the outskirts of Santiago Yolomécatl (Figs. 1 and 2) (Jiménez-Hidalgo et al., 2015, p. 40; 2018a [available online 2017], p. 427, fig. 1). The town is situated near the northwestern corner of the Yolomécatl Subbasin (= study area; see below), which, in turn, lies in northwestern Oaxaca, southern Mexico (Jiménez-Hidalgo et al., 2015, p. 40, fig. 1; 2018a, p. 427, fig. 1, Guerrero-Arenas et al. (2020, fig. 1). Because the name Iniyoo LF appeared online on December 18, 2014, and Yolomécatl and Yanhuitlán LFs did not appear until August 4, 2015, the latter two names are junior synonyms of Iniyoo LF. Therefore, Iniyoo LF has priority. Accordingly, Yolomécatl and Yanhuitlán LFs are rejected herein on those bases.

The Iniyoo LF occurs in a unit previously assigned to (1) the Yanhuitlán Formation by Jiménez-Hidalgo et al. (2011) and Ferrusquía-Villafranca and Ruiz-González (2015, p. 330, table 1, p. 326, formation 4a), (2) the Yolomécatl unit and the fossiliferous strata of Yolomécatl by Jiménez-Hidalgo et al. (2015, pp. 40, 46, fig. 2) and Jiménez-Hidalgo and Guerrero-Arenas (2015, p. 18), respectively, and (3) the Yolomécatl Formation by Ferrusquía-Villafranca et al. (2016, pp. 198, 200, fig. 4; 2018a, pp. 144–145; 2018b, p. 2; 2018c, p. 204) and Jiménez-Hidalgo et al. (2018a, p. 428) (see Appendix A regarding synonyms for units cited herein), a unit restricted to the Yolomécatl Subbasin and its immediate vicinity.

The assemblage was regarded variously as anywhere from late Tiffanian to late Chadronian and late Paleocene to late Eocene in age (North American Land Mammal Ages [NALMAs] after Wood et al., 1941, pp. 9–11, plate 1; see below). Those age assignments were based largely on (1) a Pb-alpha radiometric age determination of 49.0 ± 8.0 Ma first reported by Schlaepfer et al. (1974, p. 244, sample LG-123) for zircon crystals from a tuff sheet in the Yanhuitlán Formation; and (2) an ^{40}argon/^{39}argon (Ar/Ar) date of 43.0 ± 1.2 Ma provided by Cerca et al. (2007) for plagioclase of an andesitic laccolith that intruded the same formation (3) an Ar/Ar age of 40.3 ± 1.0 published by Ferrusquía-Villafranca et al. (2016, p. 200, table B.4, sample FV14-204; misprinted as 40.7 Ma by Ferrusquía-Villafranca et al., 2018c, p. 204); for K-feldspar crystals from a bed identified as a silicic or silicified tuff sheet reportedly lying roughly 55 m below the fossil land mammal-bearing layer in the Yolomécatl Formation; and (4) potassium-argon (K–Ar) determinations of 32.9 ± 0.9 for biotite and 35.7 ± 1.0 Ma for whole rock supplied by Martiny et al. (2000, p. 81, table 1, sample CON-101) and Santamaría-Diaz et al. (2008, p. 500, table 1 and fig. 2, sample AS-03, fig. 3) for volcanic units previously referred to the Cañada María Andesite and once believed to overlie the fossil-bearing unit (see Appendix B for uncorrected and revised radiometric dates cited herein) (Jiménez-Hidalgo et al., 2011; 2012; 2015, p. 40, fig. 2; 2018a, p. 428; Ferrusquía-Villafranca and Ruiz-González, 2015, p. 330, table 1, p. 326, formations 4a, 4b, table B.2; Jiménez-Hidalgo and Guerrero-Arenas, 2015, p. 18; Ferrusquía-Villafranca et al., 2016, p. 200, table B.4, sample FV14-204; 2018a, p. 144; 2018b, pp. 2, 7; 2018c, p. 204; Ferrusquía-Villafranca and Wang (2021, p.2, 4)).

However, and in contrast to all other authors, Jiménez-Hidalgo et al. (2018b; 2019, p. 189; see 2017), Guerrero-Arenas et al. (2020, p. 2), and Ortiz-Caballero et al. (2020, p. 1192) considered the Iniyoo LF to be of early Arikareean (= Ar1 of Woodburne, 2004, Fig. 8.6) and early Oligocene age, but correlative assemblages were considered early Arikareean in age by Tedford et al. (2004, p. 211, figs. 6.2–6.3) and earliest Arikareean by Albright et al. (2008, pp. 228–229, Figs. 10–11). Consequently, the Iniyoo LF is regarded in this report as earliest Arikareean (Ar1) and, following the 2016 and 2020 Paleogene time scales of Ogg et al. (2016, Fig. 14.5, p. 194) and Speijer et al. (2020, fig. 28.12, p. 1114), respectively, as recently modified by Cohen et al. (2013, updated 2020), later early Oligocene in age. The early Arikareean age assignments were based largely on (1) overlapping land mammal biochrons, especially first and last appearance datums, for the assemblage's constituent taxa, and (2) a uranium-lead (U–Pb) maximum depositional age of 30.6 ± 0.77 for a sandstone bed occurring in the vertebrate fossil-bearing interval reported by Jiménez-Hidalgo et al. (2018b; 2019, pp. 188–189), Guerrero-Arenas et al. (2020, p. 2), and Ortiz-Caballero et al. (2020, p. 1192) (Appendix B). Accordingly, Pb-alpha, K–Ar, and Ar/Ar dates previously used to constrain the geochronologic age of the Iniyoo LF were declared incompatible by Jiménez-Hidalgo et al. (2017) with an Arikareean age assignment.

Recent field investigations and laboratory analyses have demonstrated that the fossil-bearing Yolomécatl Formation, contrary to Ferrusquía-Villafranca and Wang (2021), actually belongs to the dominantly lacustrine Chilapa Formation (Jiménez-Hidalgo et al., 2019, p. 189, not 2015, contrary to Ferrusquía-Villafranca and Wang (2021), which overlies and interfingers with volcanic units previously identified as the Cañada María Andesite by Santamaría-Díaz et al. (2008, p. 500, fig. 3), and not to the underlying Yanhuitlán Formation. Consequently, (1) K–Ar and Ar/Ar dates for volcanic units associated with the Chilapa Formation and (2) the U–Pb maximum depositional age of 30.6 Ma reported by Jiménez-Hidalgo et al. (2018b; 2019, pp. 188–189), Guerrero-Arenas et al. (2020, p. 2), and Ortiz-Caballero et al. (2020, p. 1192) for detrital zircon crystals from a sandstone bed in the fossil-bearing interval of the Chilapa Formation must now be considered when constraining the geochronologic age of the Iniyoo LF.

This report provides additional stratigraphic evidence that indicates the fossiliferous beds of the Yolomécatl Subbasin are actually part of the Chilapa Formation. The paper also evaluates geochronologic and biochronologic data supporting an earliest Arikareean (Ar1) (i.e., later early Oligocene) instead of a latest Uintan to late Chadronian (i.e., later early middle to latest Eocene) age assignment for the Iniyoo LF.

1.1. Abbreviations

The following abbreviations, acronyms, and initialisms are used herein. **Ar** = Arikareean, **Ar1** = earliest Arikareean, **Ar2** = late early Arikareean, **Ar/Ar** = ^{40}argon/^{39}argon, **Ch** = Chadronian, **Ch2** = middle Chadronian, **Ch4** = late Chadronian, **cm** = centimeter, **CICESE** = Centro de Investigación Científica de Educación Superior de Ensenada, Departamento de Geología, Laboratorio de Geocronología, **FAD** = first appearance datum, **FCTs** = Fish Canyon Tuff sanidine, **GA-1550** = biotite, Mount Dromedary Monzonite, **IGM** = Colección Nacional de Paleontología, Instituto de Geología, Universidad Nacional Autónoma de México, Mexico City, **INEGI** = Instituto Nacional de Estadística Geográfica e Informática, **IUGS** = International Union of Geological Sciences, **K** = potassium, ^{40}**K** = ^{40}potassium, **K–Ar** = potassium-argon, **km** = kilometer, **LAD** = last appearance datum, **LF** = Local Fauna, **m** = meter, **Ma** = million years, **NACSN** = North American Commission on Stratigraphic Nomenclature, **NALMA** = North American Land Mammal Age, **Pb-alpha** = lead-alpha, **SGM** = Servicio Geológico Mexicano, **UMPE** = Colección Científica del Laboratorio de Paleobiología, campus Puerto Escondido, Universidad del Mar, and **U–Pb** = uranium-lead.

1.2. Conventions

Unless indicated otherwise, K–Ar radiometric age determinations cited herein have not been recalculated. Only those K–Ar dates deemed most pertinent to the present study and constraining the geochronologic age of the Chilapa Formation but generated by earlier dating analyses were corrected specifically for this investigation. Doing so ensured such an age (1) reflected updated IUGS decay and abundance constants recommended for use by Steiger and Jäger (1977, p. 359) in K–Ar dating analysis and (2) they were compatible with K–Ar ages produced by analyses using the same constants. Dates generated using previously

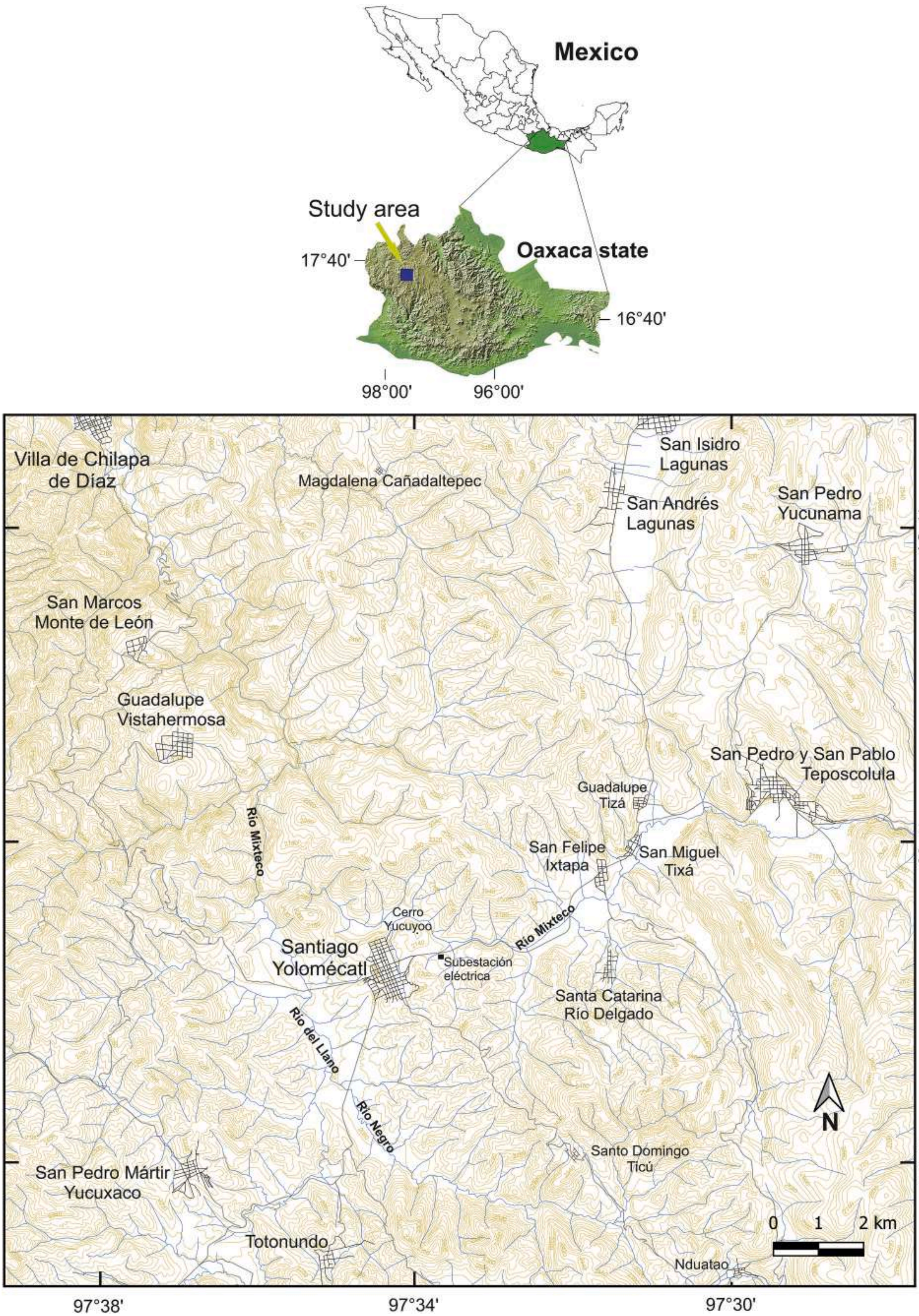

Fig. 1. Index map of current study area in northwestern Oaxaca, southern Mexico, and topographic map of Villa de Chilapa de Diaz-Santiago Yolomécatl area, including Yolomécatl Subbasin. Contour interval = 20 m. Geographic names from INEGI 2001a, 2001b.

accepted constants were recalculated with correction factors provided by Dalrymple (1979, table 2).

Similarly, Ar/Ar ages provided by Ferrusquía-Villafranca et al. (2016, p. 224, table B.4) were recalculated because they were relevant to determining the geochronologic age of the Chilapa Formation. Those dates were generated by radiometric dating analyses calibrated with GA-1550 crystals as the neutron fluence monitor or calibration standard and the corresponding, previously accepted Ar/Ar date of 98.79 ± 0.54 Ma. That age had been reported earlier by Renne et al. (1998, p. 128), who intercalibrated the date with the previously recommended age of 28.02 ± 0.16 Ma for FCTs. However, a revised date of 99.44 ± 0.17 Ma for GA-1550 was reported by Schmitz (2012, table 6.1) to account for

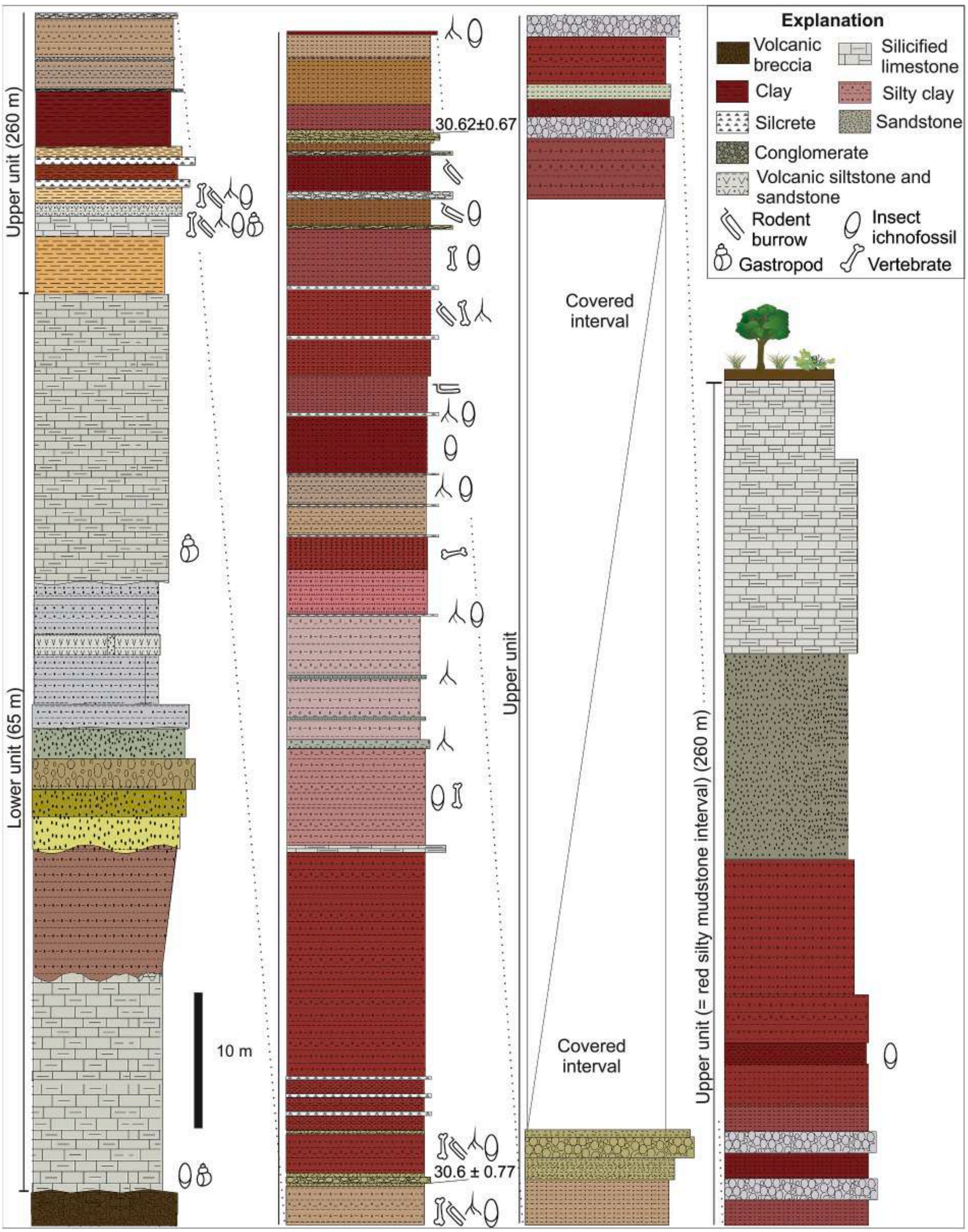

Fig. 2. Generalized stratigraphic columnar section of Chilapa Formation in Yolomécatl Subbasin. 30.6 ± 0.77 and 30.62 ± 0.67 = U–Pb ages (Ma). Compare with Guerrero-Arenas et al. (2020, p. 2).

the currently accepted, astronomically tuned Ar/Ar date of 28.201 ± 0.046 Ma recommended by Kuiper et al. (2008, p. 501) for use with the FCTs fluence monitor. Consequently, critical Ar/Ar dates provided herein were updated using the Microsoft Excel application *ArArReCalc 7/31/09* (McLean, 2009) to ensure their compliance with (1) the currently accepted date for FCTs, the revised total ^{40}K decay constant provided by Min et al. (2000, p.77, table 3) and (2) the 2016 and 2020 Paleogene time scales of Ogg et al. (2016, Fig. 14.5, p. 194) and Speijer et al. (2020, Fig. 28.12, p. 1114), respectively, as subsequently modified by Cohen et al. (2013, updated 2020). Although Ar/Ar ages provided by Cerca et al. (2007, fig. 8, table 2) are also essential in refining geochronologic age limits for the Chilapa Formation, those ages are considered uncorrected in this report because information regarding the fluence monitor used and its corresponding geochronologic age were not published previously or otherwise available. Original and recalculated K–Ar and Ar/Ar ages cited herein for units exposed in the study area and surrounding region are in Appendix B.

The Tiffanian, Uintan, Duchesnean, Chadronian, Orellan, Whitneyan, and Arikareean NALMAs cited in this report were originally characterized by Wood et al. (1941). Definitions of those ages were subsequently updated, and subdivisions of the ages were defined and their respective boundaries constrained geochronologically by Prothero and Emry (1996; 2004), Lofgren et al. (2004), Robinson et al. (2004), Tedford et al. (2004), Woodburne (2004), and Albright et al. (2008). They were based on FADs and LADs for specific land mammal taxa. Except where noted, current correlations of the NALMAs and subages with the European Paleogene epochs and subepochs and their calibration with the 2020 and 2016 Paleogene time scales follow Speijer et al. (2020, Fig. 28.12, p. 1114) and Ogg et al. (2016, fig. 14.5, p. 194).

Taxonomic identifications cited below for the land mammal specimens from the Chilapa Formation were provided by Jiménez-Hidalgo and Guerrero-Arenas (2015, pp. 18–19, table 1) and Jiménez-Hidalgo et al. (2015, 2017, 2018a [available online 2017], p. 428; 2018b; 2019, p. 188). Although such identifications have not been revised for this report, respective FAD and LAD data have been updated as necessary.

1.3. Objectives

This contribution has the following objectives: (1) presenting preliminary, recently compiled lithostratigraphic and biostratigraphic data supporting assignment of the fossil-bearing unit in the Yolomécatl Subbasin to the Chilapa Formation, (2) clarifying the stratigraphic relations of that formation and associated volcanic units in and near the subbasin, (3) correcting and reviewing some radiometric age determinations for the volcanic units, (4) supplying additional information on U–Pb maximum depositional ages and the respective samples from the Chilapa Formation, (5) providing current biochronologic data, especially FADs and LADs, for age-diagnostic land mammal taxa constituting the Iniyoo LF, and (6) integrating stratigraphic, geochronologic, and biochronologic data to allow development of an accurate and well-constrained estimate for the geochronologic age of the Iniyoo LF. Doing so will substantiate previous, early (or earliest) Arikareean (Ar1), and later early Oligocene age assignments for the assemblage by Jiménez-Hidalgo et al. (2018b; 2019, p. 189), Guerrero-Arenas et al. (2020, p. 2), and Ortiz-Caballero et al. (2020, p. 1191).

2. Geographic, physiographic, and structural settings

Taxa constituting the Iniyoo LF are represented by continental vertebrate remains, particularly bones and teeth of land mammals, from several IGM and UMPE fossil localities in the outskirts of Santiago Yolomécatl in northwestern Oaxaca, southern Mexico (Fig. 1) (Jiménez-Hidalgo et al., 2015, p. 40, Fig. 1; 2018a, p. 427, Fig. 1; Guerrero-Arenas et al., 2020, fig. 1). Santiago Yolomécatl and the surrounding study area occur in the Tierras Altas de Oaxaca Subprovince of the Sierra Madre del Sur Physiographic Province (Jiménez-Hidalgo et al., 2015, p. 40).

According to Jiménez-Hidalgo et al. (2015, p. 40, fig. 1b), the corresponding fossil-bearing strata are exposed in the basin of Yolomécatl, which lies in the southeastern part of a major structural depositional basin, the Tlaxiaco Basin. The southeastern part of that physiographic feature was referred to as the Yolomécatl Graben or the Yolomécatl Basin/Graben by Ferrusquía-Villafranca et al. (2016, p. 205, Fig. 9) and the Yolomécatl Basin or the Yolomécatl Tectonic Basin by Ferrusquía--Villafranca et al. (2018a, pp. 144, 153, fig. 2b; 2018b, p. 2, fig. 2b). The roughly triangular Yolomécatl Basin (= Block B of Ferrusquía-Villafranca et al., 2018a, fig. 6) corresponds to the Yolomécatl Subbasin herein and the present study area, with Santiago Yolomécatl and the fossil localities lying near the subbasin's northwestern corner (Fig. 1) (Jiménez-Hidalgo et al., 2018a, Fig. 1; Guerrero-Arenas et al., 2020, fig. 1). The subbasin was reported by Ferrusquía-Villafranca et al. (2016, fig. 9; 2018a, p. 147, fig. 6) as bounded to the north by the Teposcolula Fault, by the Ticú Fault to the east, and to the south and west by the Río Negro and Río Mixteco faults, respectively. Ticú Dome and Santo Domingo Ticú are just beyond and east of the southern corner of the subbasin. Similarly and as mapped by Ferrusquía-Villafranca et al. (2016 and 2018a, fig. 1), the Yolomécatl Subbasin was also bordered to the north by the Río Teposcolula (= Río Mixteco as used herein, following INEGI, 2001a) and to the south and west by the Río Negro and Río del Llano. Faults were shown closely paralleling the corresponding drainages. However, the Río del Llano, Río Mixteco and Río Negro valleys were mapped by Ferrusquía-Villafranca et al. (2016, fig. 3; 2018a, fig. 2a; 2018b, figs. 2, 2018c and fig. 1) as mostly and entirely floored by Quaternary alluvial deposits. Consequently, existence of the corresponding faults could not be verified during our field surveys (see below).

3. Previous work

3.1. Stratigraphy

Ferrusquía-Villafranca (1976, plate 14) mapped a large area of northwestern Oaxaca lying north of 17° 30′ North Latitude, east of 97° 40′ West Longitude, and immediately north of the Yolomécatl Subbasin (= present study area; see above). Cerca et al. (2007, fig. 7) mapped much of the same area located north of 17° 29′ North Latitude and west of 97° 15′ West Longitude, but also included the northern margin of the subbasin. Their mapping was based on maps provided by González-Ramos et al. (2000) and Martínez-Amador et al. (2001). Ferrusquía-Villafranca et al. (2016, fig. 3) mapped a similarly large area, but one (1) situated mostly to the south and offset a bit to the west, (2) lying south of 17° 32′ North Latitude and west of 97° 28′ West Longitude, and (3) including Santiago Yolomécatl and the Yolomécatl Basin or Graben (= Yolomécatl Subbasin and current study area of this report; see above) near the center of his map area's northeastern quadrant. The region of overlapping coverages, which is bounded by 17° 29′ and 17° 32′ North Latitudes and 97° 40′ and 97° 28′ West Longitudes, lies immediately east of San Sebastián Nicananduta and just north of Santiago Yolomécatl, but includes Guadalupe Vista Hermosa, San Felipe Ixtapa, San Miguel Tixá, and San Pedro y San Pablo Teposcolula. Much of the region encompassed by those three studies was also mapped by the INEGI (1994) and Santamaría-Díaz et al. (2008, fig. 2). Recently, the Mexican Geological Service published the Carta Geológico-Minera Santiago Yolomécatl (Márquez-Pérez et al., 2020), which is based on previous geologic mapping.

A thick succession of Paleogene lacustrine, fluviolacustrine, and associated volcanic units were recognized in the area mapped by Ferrusquía-Villafranca (1976, pp. 23, 26, 30–35, 39, 41, 47–51, 60, 62, 66–67, 73, fig. 3, plates 14–16). In order of increasing stratigraphic position, those units, most of which were new, include (1) the Tamazulapan Conglomerate (new), which is separated from the underlying late Cretaceous marine Yucunama Formation by an angular unconformity, (2) the unconformably overlying fluviolacustrine Yanhuitlán Formation, (3) the conformably overlying Llano de Lobos Tuff (new), (4) the conformably overlying Cerro Verde Tuff (new), (5) the unconformably overlying Yucudaac Andesite (new), which locally overlies the Yanhuitlán Formation unconformably where the intervening Llano de Lobos and Cerro Verde Tuffs are absent, (6) the San Marcos Andesite (new), which unconformably overlies the Yanhuitlán Formation and is in fault contact with the Yucudaac Andesite, and (7) the mostly lacustrine Chilapa Formation (new), which (7a) overlies the lowermost flow or lower tongue of the Yucudaac Andesite and, where intervening volcanic units are not present, unconformably overlies the Yanhuitlán Formation, but (7 b) interfingers with the upper parts of the San Marcos and Yucudaac Andesites. Although mapping by Ferrusquía-Villafranca (1976, plate 14) did not cover the Yolomécatl Subbasin, Erben (1956, p. 54) had earlier recognized the Yanhuitlán Formation as occurring in the Santiago Yolomécatl area (Appendix A).

The INEGI (1994) subsequently mapped the Huajuapam Formation (= unit Ti [cz]) and the Yanhuitlán Formation (= units Ti [lm-ar], Ti [ar-cg]) as separate units in the Yolomécatl Subbasin (Appendix A) and the substantial region to the north. However and in contrast to Ferrusquía-Villafranca (1976, plate 14), they did not recognize the Chilapa Formation in the latter area as a unit distinct from the other two. Similarly, all Tertiary andesitic or volcanic units of the region were mapped together as late Oligocene to early Miocene andesite (= unit Tom [A]). González-Ramos et al. (2000) later mapped all Tertiary sedimentary units in the region as Paleogene polymictic conglomerate and sandstone (= unit TpaeCgp-Ar), whereas overlying volcanic units were mapped as Neogene andesite and andesitic tuff (= unit TemTA-A) (Appendix A).

On the other hand, Cerca et al. (2007, fig. 7), based on mapping by González-Ramos et al. (2000) and Martínez-Amador et al. (2001), mapped the Yanhuitlán Formation as the only Paleogene epiclastic unit along the northern edge of the Yolomécatl Subbasin and in the area to the north, and volcanic units were also mapped together. Although the Chilapa Formation was not mapped as a separate unit, it was recognized as a distinct formation overlying and interfingering with the Yucudaac Andesite in a stratigraphic columnar section of the region (Cerca et al., 2007, fig. 8). Similarly, the Yucudaac Andesite was shown overlying the Llano de Lobos Tuff, which, in turn, overlies the Yanhuitlán Formation (Cerca et al., 2007, fig. 8).

Unlike Cerca et al. (2007, fig. 7), Santamaría-Díaz et al. (2008, p. 500, figs. 2–3) identified and mapped most of the Paleogene units recognized by Ferrusquía-Villafranca (1976, plate 14), but recognized a new one as well. Those units included (1) the Yanhuitlán Formation, (2) the overlying Cañada María Andesite (new, but undefined), and (3) the Chilapa Formation (Appendix A), which interfingers with the Cañada María Andesite and underlies the Yolomécatl Subbasin and much of the area to the north in their fig. 2.

Based on previous mapping by Cerca et al. (2007, fig. 7) and superficially similar texture and color of the respective sediments but contrary to subsequent mapping by Santamaría-Díaz et al. (2008), fossil-bearing strata exposed in the outskirts of Santiago Yolomécatl (i.e., in Yolomécatl Subbasin) that contain the Iniyoo LF (= Yolomécatl or Yanhuitlán LF; see above) were assigned to the Yanhuitlán Formation instead of the Chilapa Formation by Jiménez-Hidalgo et al. (2011), but only questionably by Ferrusquía-Villafranca and Ruiz-González (2015, p. 330, table 1, p. 326, formation 4a). The fossiliferous unit was presumably referred to the Yanhuitlán Formation by the last authors because it was overlain by a volcanic unit identified and mapped by Santamaría-Díaz et al. (2008, figs. 2–3) as the Cañada María Andesite, which overlies the Yanhuitlán Formation in the Yolomécatl Subbasin and vicinity.

Contrary to authors cited above, the upper 240 m of the sedimentary sequence conformably underlying the Cañada María Andesite were referred to informally as the fossiliferous strata of Yolomécatl and the Yolomécatl unit by Jiménez-Hidalgo and Guerrero-Arenas (2015, p. 18) and Jiménez-Hidalgo et al. (2015, p. 40, fig. 2), respectively (Appendix A). However, the latter authors still assigned the lower 300–600 m of the succession to the Yanhuitlán Formation, which was shown conformably underlying the Yolomécatl unit. As so recognized, the Yolomécatl unit represented a distinct set of strata lying between the Yanhuitlán Formation and the Cañada María Andesite. The Yolomécatl unit fills the basin of Yolomécatl (= Yolomécatl Subbasin herein and present study area). It includes a 200-m-thick, fossil-bearing, dominantly mudstone interval that overlies a basal, 40-m-thick, thickly bedded, partially silicified, and comparatively resistant limestone unit. In contrast to the Yanhuitlán Formation, the Yolomécatl unit contains abundant paleosol horizons, and beds are much thicker or approximately 1 m or more in thickness.

Ferrusquía-Villafranca et al. (2016, pp. 191, 196–198, 200–202, figs. 3–4) mapped a thick sequence of Paleogene lacustrine, fluviolacustrine, and associated volcanic units, most of which were new, in the large area of northwestern Oaxaca that included the Yolomécatl Subbasin and the surrounding region in its northeastern portion (see above). However, just two of the respective units, the Tamazulapam (or Tamazulapan) Conglomerate and the Chilapa Formation, were also recognized and mapped by Ferrusquía-Villafranca et al. (1976, plate 14) in the region lying mostly to the north. The mapped units particularly important to the current investigation included (1) the volcanic Nduayaco "Group" (new), which was thought to overlie the Tamazulapam Conglomerate, (2) the 250-m-thick fossil-bearing fluviolacustrine Yolomécatl Formation, which was believed to unconformably overlie the Nduayaco "Group" (e.g., along eastern margin of subbasin), although the respective contact was not exposed, and to be a correlative of the Huajuapam and conformably overlying Yanhuitlán Beds of Salas (1949, pp. 119, 123, figs. pp. 119, 122), (3) the Tayata Pyroepiclastics, which apparently also overlies the Nduayaco "Group" and resembles the Yolomécatl Formation in general appearance, (4) the volcanic Nundichi "Group" (new), which is separated from the underlying Tayata Pyroepiclastics by a paraunconformity, (5) the volcanic Nicananduta "Group" (new), a correlative of the Yucudaac Andesite that unconformably overlies the Yolomécatl Formation at the northwestern corner of the Yolomécatl Subbasin about 2.25 (not 4.5) km northwest of Santiago Yolomécatl) and at greater distances from the Yolomécatl Subbasin, the Nundichi "Group," and (6) lacustrine strata assigned questionably to the Chilapa Formation, which was presumed to intertongue locally with the Nicananduta "Group" and to overlie the Yolomécatl Formation unconformably where the Nicananduta "Group" was absent, but was found to interfinger with the upper part of the San Marcos Andesite north of the subbasin.

According to Ferrusquía-Villafranca et al. (2016, table B.1), (1) the Nduayaco, Nundichi, and Nicananduta "Groups" were previously mapped together as the undefined Cañada María Andesite by Santamaría-Díaz et al. (2008, fig. 2), (2) the Tayata Pyroepiclastics were mapped as the Yanhuitlán Formation, and (3) the Yolomécatl Formation was mapped as the Chilapa Formation, but also included units mapped earlier by the INEGI (1994) (i.e., lower Tertiary freshwater limestone, siltstone and sandstone, and sandstone and conglomerate) and González-Ramos et al. (2000) (i.e., Paleocene to Eocene polymictic conglomerate and sandstone) and equated with the Huajuapam and Yanhuitlán Beds. Of those units, (1) the Nduayaco and Nundichi "Groups" were based on volcanic rocks of the Santa María Nduayaco and Santiago Nundichi areas, which lie east-southeast and southwest, respectively, of the Yolomécatl Subbasin, (2) the Nicananduta "Group" was founded on volcanic rocks in the San Sebastián Nicananduta area northwest of the subbasin, but also included similar rocks in the Cañada María area west of the Yolomécatl Subbasin and approximately 2.25 (not 4.5) km northwest of Santiago Yolomécatl (i.e., near northwestern corner of subbasin), and (3) the Tayata Pyroepiclastics were founded on dominantly epiclastic strata exposed between Santa Cruz Tayata and Santa Catarina Tayata and extending from just west to far south of the Yolomécatl Subbasin (Ferrusquía-Villafranca et al., 2016, pp. 198, 200–201, fig. 3). On the other hand, the Yolomécatl Formation was based on type and principal reference sections situated only a few kilometers south to south-southwest of Santiago Yolomécatl and occupying a small triangular fault-bounded basin (i.e., Yolomécatl Basin or Graben = Yolomécatl Subbasin herein) (Ferrusquía-Villafranca et al., 2016, pp. 198, 204–205, fig. 3, cross section A–A', fig. 9).

Jiménez-Hidalgo et al. (2018a, p. 428) followed Ferrusquía-Villafranca et al. (2016, pp. 198, 200) in assigning the Yolomécatl unit to the Yolomécatl Formation. The approximately 40-m-thick fossil-bearing interval lies in the middle and about 100 m below the top (or 110 m above the base) of the roughly 250-m-thick mudstone sequence, which overlies the basal, partially silicified (and 40-m-thick; see above) limestone unit (i.e., formation was about 290 m thick). Unlike those authors, Jiménez-Hidalgo et al. (2017, 2018b) did not specify the formation to which the fossiliferous strata belonged in either of two other recent publications.

Ferrusquía-Villafranca et al. (2018a, pp. 144–145, figs. 2–3; 2018b, p. 2, figs. 2–3; 2018c, p. 204, fig. 1) recognized most of the same Paleogene units as Ferrusquía-Villafranca et al. (2016, fig. 4) in the Santiago Yolomécatl area (i.e., Nduayaco "Group," Yolomécatl Formation, Nundichi and Nicananduta "Groups," and Chilapa Formation), but considered the Yolomécatl Formation to be roughly 650 m instead of approximately 250 m thick. However, only about 250 m of continuous section could be measured (Ferrusquía-Villafranca et al., 2018a, p, 144). Ferrusquía-Villafranca et al. (2018a, p. 144–145, Fig. 2b) referred to the Yolomécatl Subbasin as the Yolomécatl Tectonic Basin (= Block B in their fig. 6), but incorrectly stated that the Yolomécatl Formation was unconformably overlain by the Nundichi "Group." They also reported that the Nduayaco "Group" unconformably underlies the Yolomécatl Formation, even though the respective contact was not exposed.

Although nearly all earlier authors referred the fossil-bearing unit in the Yolomécatl Subbasin to the Yanhuitlán or Yolomécatl Formation, Jiménez-Hidalgo et al. (2019, p. 189) reassigned the unit to the Chilapa Formation (Appendix A), as it was originally mapped therein by Santamaría-Díaz et al. (2008, fig. 2). That assignment relied on textural, mineralogical, and infrared analyses conducted as part of the present investigation. Consequently, lithologic similarities of the fossil-bearing interval in the Yolomécatl Subbasin and the Chilapa Formation to the north must be documented, and stratigraphic relations and identities of volcanic units associated with the Chilapa Formation in the Yolomécatl Subbasin and its immediate vicinity must also be reevaluated, based on results of field studies.

3.2. Geochronology

Schlaepfer et al. (1974, p. 244) regarded the Yanhuitlán Formation as middle? Eocene in age (see above regarding stratigraphic units discussed in this section) and Ferrusquía-Villafranca (1976, p. 39) considered it to be of late Paleocene to middle Eocene age, relying on a Pb-alpha date of 49.0 ± 8.0 Ma for an interbedded pumiceous tuff sheet (Appendix B) exposed in San Pedro Sayultepec, which lies 29.9 km east of the Yolomécatl Subbasin. According to Ferrusquía-Villafranca and Ruiz-González (2015, table 1, p. 326, formation 4a), the analysis was conducted on zircon crystals collected in the area of 17° 30′ North Latitude and 97° 20′ West Longitude. As mapped by Martiny et al. (2000, Fig. 4), Cerca et al. (2007, fig. 7), and Santamaría-Díaz et al. (2008, fig. 2), that area, which includes Santo Domingo Yanhuitlán, is underlain mostly by the Yanhuitlán Formation. The date led Ferrusquía-Villafranca and Ruiz-González (2015, table 1, p. 326, formation 4a) to conclude that the fossil-bearing Yanhuitlán Formation of the Yolomécatl Subbasin was of late Paleocene to middle Eocene or late Tiffanian to early Uintan age. However, those authors appear to have questioned the reliability of the date because of its 8-Ma error. The date almost certainly represents a maximum depositional age for detrital zircon grains, but it was presumably rejected by Ferrusquía-Villafranca et al. (2016), who did not cite the date in that or subsequent reports. Nevertheless, it is clearly compatible with the K–Ar date of 40.5 ± 1.7 Ma provided by Martiny et al. (2000, p. 78, table 1, sample CON-7) and the uncorrected Ar/Ar date of 43.0 ± 1.2 Ma reported by Cerca et al. (2007, pp. 15–16, table 2, sample YAN-7 all, fig. 8), for an andesitic laccolith intruding the Yanhuitlán Formation (Appendix B).

Ferrusquía-Villafranca and Ruiz-González (2015, p. 330, table 1, p. 326, formations 4b–4d) also regarded the Yanhuitlán Formation as late middle Eocene or minimally late or latest Eocene and questionably Duchesnean to Chadronian in age when relying on several other radiometric age determinations. Such determinations included (1) the K–Ar date of 40.5 ± 1.7 Ma and the uncorrected Ar/Ar date of 43.0 ± 1.2 Ma for the laccolith intruding the Yanhuitlán Formation and (2) a K–Ar age of 35.7 ± 1.0 Ma reported by Santamaría-Díaz et al. (2008, p. 500, table 1, figs. 2–3) for their sample AS-03 from the Cañada María Andesite, several meters below the Chilapa Formation (Appendix B).

Similarly, the same fossil-bearing unit (then identified as Yolomécatl Formation) was considered (1) early late Eocene or latest Uintan to earliest Duchesnean in age by Ferrusquía-Villafranca et al. (2016, p. 200, but early Oligocene in table B.1, p. 220; 2018a, p. 144) and (2) of Bartonian and late middle Eocene or latest Uintan age by Ferrusquía-Villafranca et al. (2018b, p. 2; 2018c, p. 204). Those age assignments were based on an uncorrected Ar/Ar date of 40.3 ± 1.0 Ma reported by Ferrusquía-Villafranca et al. (2016, p. 200, table B.4, sample FV14-204) for K-feldspar crystals from a bed identified as a silicic or silicified tuff sheet in the Yolomécatl Formation (Appendix B). That date was generated by Ar/Ar analysis using GA-1550 biotite crystals as the fluence monitor and the corresponding, previously recognized Ar/Ar age of 98.79 ± 0.54 Ma (Ferrusquía-Villafranca et al., 2016, p. 224; see above). However, the date for the tuff sheet is recalculated in this report as 40.561 ± 1.009 Ma using the previously recommended and intercalibrated age of 28.02 ± 0.16 Ma for FCTs and *ArArRecalc 7/31/09* (Appendix B; see above). Geographic coordinates provided by Ferrusquía-Villafranca and Ruiz-González (2015, table 1, p. 326, formation 4a) and Ferrusquía-Villafranca et al. (2016, table B.4, sample FV14-204) and geologic mapping in Martiny et al. (2000, fig. 4) and Santamaría-Díaz et al. (2008, fig. 2) indicate that the tuff sheet Ar/Ar dated at 40.3 ± 1.0 Ma in age is part of the Chilapa Formation and not the underlying Yanhuitlán Formation, which encompasses the tuff sheet dated at 49.0 ± 8.0 Ma by Pb-alpha analysis (see above).

In contrast to age assignments provided by the authors just cited, the Iniyoo LF was originally regarded, sometimes minimally, as Chadronian or Priabonian and late Eocene in age by Jiménez-Hidalgo et al. (2011, 2012; 2015, pp. 40–41; 2018a, p. 428) and Jiménez-Hidalgo and Guerrero-Arenas (2015, pp. 18–19). Those age assignments were based primarily on K–Ar dates of 32.9 ± 0.9 and 35.7 ± 1.0 Ma for volcanic units then identified as the Cañada María Andesite and thought to conformably overlie the fossil-bearing unit (i.e., Yanhuitlán or Yolomécatl Formation) in the Yolomécatl Subbasin (see below). However, exposures of the Cañada María Andesite at and just beyond the northwestern corner of the Yolomécatl Subbasin were reassigned by Ferrusquía-Villafranca et al. (2016, p. 201, fig. 3) to the Nicananduta "Group," which unconformably overlies the Yolomécatl Formation at the northwestern corner of the subbasin and intertongues with the Chilapa Formation north of the subbasin. The Nicananduta "Group" was 27.7 ± 0.7 (or 27.65 ± 0.71) Ma (uncorrected date) and late Oligocene in age, based on Ar/Ar radiometric dating analysis (Ferrusquía-Villafranca et al., 2016, p. 201, table B.4, sample FV14-174, fig. C1). The K–Ar date of 32.9 ± 0.9 Ma was provided by Martiny et al. (2000, p. 81, table 1, sample CON-101) for a pyroclastic unit Ferrusquía-Villafranca et al. (2016, p. 201, figs. 3–4, table B.1, p. 221, table B.4, sample CON-101) subsequently named the Nundichi "Group," which unconformably underlies the Nicananduta "Group" west-northwest to south of the Yolomécatl Subbasin (Appendices A, B). Although the K–Ar age of 35.7 ± 1.0 Ma was originally reported for the Cañada María Andesite by Santamaría-Díaz et al. (2008, p. 500, table 1 and fig. 2, sample AS-03, fig. 3), Ferrusquía-Villafranca et al. (2016, p. 201, but not table B.4, sample AS-3) later identified the dated unit as the Yucudaac Andesite, relying on geographic coordinates for the respective sampling site provided by Santamaría-Díaz et al. (2008, table 1, sample AS-03).

The lowermost flow or lower tongue of the Yucudaac Andesite (1) overlies the Yanhuitlán Formation unconformably where the intervening Llano de Lobos and overlying Cerro Verde Tuffs are absent, (2) unconformably overlies the latter two tuffaceous units where present below the andesite, and (3) underlies the Chilapa Formation, whereas (4) the upper part of the Yucudaac Andesite interfingers with the Chilapa Formation (Ferrusquía-Villafranca, 1976, pp. 50–51, 59–60, 67, 73). However, Ferrusquía-Villafranca et al. (2016, p. 201) considered the date of 35.7 ± 1.0 Ma incompatible with two other uncorrected K–Ar ages of 28.2 ± 0.6 and 29.6 ± 0.6 Ma reported for sample fractions FV69-182 (whole rock) and FV69-182 from the Yucudaac Andesite's lowermost flow or lower tongue by Ferrusquía-Villafranca et al. (1974, pp. 257–258, table 2; 2016, p. 201, table B.4) and Ferrusquía-Villafranca (1976, p. 45, table 7) (Appendix B).

Ferrusquía-Villafranca et al. (1974, p. 257, table 2; 2016, p. 201, table B.4, p. 221) and Ferrusquía-Villafranca (1976, p. 48, table 7) provided uncorrected K–Ar dates of 25.9 ± 0.5 and 26.5 ± 1.0 Ma with a mean age of 26.2 ± 0.5 Ma for their sample fractions FV69-180 and FV69-180 biotita (= biotite) from the Llano de Lobos Tuff (Appendix B), which lies unconformably between the underlying Yanhuitlán Formation and the overlying Chilapa Formation. Cerca et al. (2007, p. 16, Fig. 8, table 2, samples TAM-1 all, TAM-5 all), reported uncorrected ages Ar/Ar dated of 30.0 ± 0.8 and 31.6 ± 1.0 for the Llano de Lobos Tuff (Appendix B). According to the latter authors, the age of 30.0 ± 0.8 Ma was consistent with the tuff's stratigraphic position, but the earlier reported mean age of 26.2 Ma was not (i.e., it appeared too young). The latter date suggestes a loss of ^{40}argon from the respective sample.

Relying on the uncorrected Ar/Ar date of 40.3 ± 1.0 for the silicic or silicified tuff sheet in the Yolomécatl Formation reportedly lying 55 m below the fossil land mammal-bearing layer, Ferrusquía-Villafranca et al. (2018b, p. 2) specifically discounted the previous Chadronian age assignment for the formation by Jiménez-Hidalgo et al. (2015, pp. 40–41, 46). On the other hand, a U–Pb maximum depositional age of 30.6 Ma for detrital zircon crystals from a sandstone bed in the fossiliferous interval now assigned to the Chilapa Formation (Appendix B) was regarded by Jiménez-Hidalgo et al. (2018b; 2019, pp. 188–189), Guerrero-Arenas et al. (2020, p. 2) and Ortiz-Caballero et al. (2020, p. 1192) as consistent with early Arikareean (Ar1) and early or late early Oligocene age assignments for the formation based partly on biochronologic data. U–Pb data are discussed at length below. Those data, along with K–Ar and Ar/Ar ages for volcanic units bracketing the Chilapa Formation, must be reevaluated and K–Ar and Ar/Ar ages corrected as necessary when attempting to constrain the geochronologic age of the formation and the Iniyoo LF.

3.3. Biochronology of Iniyoo Local Fauna

The Iniyoo LF was initially regarded as Chadronian or Priabonian and late Eocene in age by Jiménez-Hidalgo et al. (2011, 2012; 2015, p. 46; 2018a, p. 428) and Jiménez-Hidalgo and Guerrero-Arenas (2015, p. 19). That age assignment was based partly on the presence in the assemblage of a few age-diagnostic land mammal taxa, which, in turn, were represented by IGM and UMPE specimens then thought to have been found in the Yanhuitlán Formation or the overlying Yolomécatl Formation (= Chilapa Formation; see above) of the Yolomécatl Subbasin. For example, Jiménez-Hidalgo and Guerrero-Arenas (2015, p. 19) and Jiménez-Hidalgo et al. (2015, p. 46; 2018a, p. 428) cited the occurrence of the equid *Miohippus assiniboiensis* when assigning the local fauna to the Chadronian NALMA. *Miohippus assiniboiensis* was considered a Chadronian index species by Jiménez-Hidalgo et al. (2018a, p. 428). Although, Jiménez-Hidalgo et al. (2015, pp. 45–46) noted that several of the taxa (e.g., tayassuid *Perchoerus*, leptochoerid *Leptochoerus*, *M. assiniboiensis*, and rhinocerotid *Trigonias*) had been recorded previously in Chadronian assemblages from the northern and central Great Plains, the presence of *M. assiniboiensis* suggested the Iniyoo LF was of middle to late Chadronian (Ch2–Ch4) and late Eocene age. That species had been regarded earlier as middle to late Chadronian in age by Prothero and Shubin (1989, p. 164), who reported it from Saskatchewan, Wyoming, and North Dakota, and South Dakota. Nevertheless, such age assignments for the Iniyoo LF were based primarily on K–Ar dates of 32.9 ± 0.9 and 35.7 ± 1.0 Ma reported by Martiny et al. (2000, p. 81, table 1, sample CON-1) and Santamaría-Díaz et al. (2008, p. 500, fig. 3, sample AS-03), respectively (Appendix B), for volcanic units then identified as the Cañada María Andesite and thought to conformably overlie the fossil-bearing unit in the Yolomécatl Subbasin (see Jiménez-Hidalgo and Guerrero-Arenas, 2015, p. 18; Jiménez-Hidalgo et al., 2012; 2015, p. 40; 2017; 2018a, p. 428).

In contrast to those authors just cited, Ferrusquía-Villafranca and Ruiz-González (2015, p. 330, table 1, p. 326, formation 4a) speculated initially that the Yolomécatl or Yanhuitlán LF (= Iniyoo LF; see above), then thought to have been associated with the Yanhuitlán Formation, was of late Tiffanian to early Uintan or late Paleocene to middle Eocene age. That age assignment was based on a Pb-alpha date of 49.0 ± 8.0 Ma for zircon crystals from a tuff sheet they believed to have been part of the fossil-bearing unit (Appendix B). However, the fossil-bearing interval is encompassed by the overlying Chilapa Formation (see above). Moreover, the authors appear to have questioned the reliability of the age determination because of its large 8-Ma error. As discussed above, that date almost certainly represents a maximum depositional age for detrital zircon grains. Because the date's reliability was considered suspect, it was concluded in the same paper (Ferrusquía-Villafranca and Ruiz-González, 2015, p. 330, table 1, p. 326, formations 4b–4d, table B2) that the assemblage was, instead, questionably Duchesnean to Chadronian or late Eocene in age. The latter age assignments were based on K–Ar date of 40.5 ± 1.7 and uncorrected K–Ar date of 43.0 ± 1.2 Ma for a laccolith intruding the Yanhuitlán Formation and the K–Ar date of 35.7 ± 1.0 Ma for the overlying Cañada María Andesite (Appendix B), an undefined unit. Unfortunately, the latter authors did not provide definitive biochronologic data to substantiate such an age assignment, noting only that the assemblage had a late Eocene appearance.

The Yolomécatl LF was subsequently regarded as (1) latest Uintan to earliest Duchesnean and early late Eocene in age by Ferrusquía-Villafranca et al. (2016, p. 200), (2) early late Eocene in age by Ferrusquía-Villafranca et al. (2018a, p. 144), (3) late or latest Uintan and Bartonian or late middle Eocene in age by Ferrusquía-Villafranca et al. (2018b, pp. 2, 7; 2018c, p. 204), and (4) possibly of latest Uintan to Duchesnean and latest late middle Eocene) age by Ferrusquía-Villafranca and Wang (2021, p. 2). However, those age assignments were based, not on biochronologic data, but, again, on an uncorrected Ar/Ar determination of 40.3 ± 1.0 Ma they reported for a bed identified as a silicic or silicified tuff sheet associated with the fossil-bearing unit (Appendix B), now identified as the Chilapa Formation. Despite spanning a 6-m-thick interval, the fossil-bearing interval (unit 20 of Ferrusquía-Villafranca et al., 2018a, fig. 4, table 1), which produced the two IGM specimens of the sciurid *Douglassciurus oaxacaensis* and the zetamyid *Protozetamys mixtecus* described by Ferrusquía-Villafranca et al. (2018b, pp. 2, 7), reportedly lies approximately about 55 m above the silicified tuff sheet (unit 1 of Ferrusquía-Villafranca et al., 2018a, fig. 4, table 1) (but see below regarding lithology of dated unit). Ferrusquía-Villafranca and Wang (2021, p. 9) recently reported another taxon, the mustelid *Oaxacagale ruizi*, which was collected about 55–65 m above the silicified tuff sheet. The UMPE fossil specimens were probably recovered from an interval that encompassed the one in which the IGM specimens were found.

On the other hand and unlike all earlier and some contemporary authors, Jiménez-Hidalgo et al. (2017) regarded the Iniyoo LF as no older than Arikareean or about 30.0 Ma in age based on the association of the geomyid *Gregorymys*, the dominantly early Arikareean or Oligocene oreodontid *Oreodontoides oregonensis*, and the hypertragulid

Nanotragulus. Subsequently, Jiménez-Hidalgo et al. (2018b; 2019, p. 188) considered the assemblage to be of early Arikareean (Ar1) and late early Oligocene age. Arikareean index taxa shared with assemblages to the north in the central and western United States included the canid *Cormocyon* and *O. oregonensis*. Taxa with Arikareean FADs comprised the lagomorph *Archaeolagus* (not Orellan or Whitneyan, contrary to Woodburne, 2004, p. 330), *Gregorymys*, Jimomyidae, the amphicyonid *Mammacyon*, and "Nothokematinae" (Camelidae). Those with Arikareean LADs consisted of the tayassuid *Perchoerus probus*, the leptochoerid *Leptochoerus*, *Nanotragulus*, and the rhinocerotid *Subhyracodon* instead of *Trigonias*. However, the age of the Iniyoo LF was further constrained to the geochron spanning the interval approximately 28.0–29.0 Ma ago by the *Mammacyon* FAD and the *P. probus* and *Subhyracodon* LADs (Jiménez-Hidalgo et al., 2018b; 2019, p. 188). Correlative assemblages occurred in north-central Oregon and the central Great Plains of the United States. Accordingly, they considered an early Arikareean age assignment for the Iniyoo LF incompatible with K–Ar dates of 32.9 ± 0.9 and 35.7 ± 1.0 Ma for volcanic units still thought to represent the Cañada María Andesite (Appendix B) and the one overlying the fossil-bearing interval (see above). Those dates suggested the dated volcanic unit(s) was Chadronian to Orellan in age. Using the same biochronologic data, Jiménez-Hidalgo et al. (2019, p. 189) reached similar conclusions regarding the age of the Iniyoo LF, regarding it as taxonomically most similar to land mammal assemblages from the Turtle Cove Member of the John Day Formation in north-central Oregon and, to a lesser extent, the Upper Sharps Formation of southwestern South Dakota.

4. Revised stratigraphy of Yolomécatl Subbasin and immediate vicinity

4.1. Statuses of Yolomécatl and Chilapa Formations

As described and mapped by Ferrusquía-Villafranca et al. (2016, pp. 197–198, 200, 202, figs. 3–4, 9, table B.1, p. 220; 2018a, pp. 144–145, figs. 2a–3, 6; 2018b, figs. 2–3, 2018c, fig. 1) and shown in cross sections of the Yolomécatl Subbasin, the Yolomécatl Formation was unconformably underlain by the Nduayaco "Group" (1) along the Río Negro (or their Río Negro Fault), the southern boundary of the subbasin, and (2) along the subbasin's eastern margin (or their Ticú Fault). On the other hand, the Yolomécatl Formation was unconformably overlain by (1) a small outlier of the Nicananduta "Group" at the northwestern corner of the subbasin, approximately 2.25 (not 4.5) km northwest of Santiago Yolomécatl and immediately south of the Río Mixteco (or their Teposcolula Fault), the subbasin's northern border and (2) a unit identified, initially only questionably, as the Chilapa Formation, presumably along the Río Mixteco and about 1.5 km northeast of Santiago Yolomécatl. However, the Yolomécatl and Chilapa Formations were only shown in fault contact at that location (i.e., along Teposcolula Fault) in their map figures and were not shown in contact anywhere else. The Chilapa Formation, (1) like the Yolomécatl Formation, also overlies the Nduayaco "Group" unconformably, but, northeast of the Yolomécatl Subbasin and immediately northwest of the Río Mixteco (or their Teposcolula Fault) near San Miguel Tixá, (2) apparently interfingers with the Nicananduta "Group."

In contrast to mapping by those workers, field surveys conducted in support of the current investigation found no evidence of their Teposcolula Fault along the Río Mixteco and the northern edge of the Yolomécatl Subbasin. Moreover, strata assigned to the Chilapa Formation along the northern side of the Río Mixteco were found to be continuous with those identified as the Yolomécatl Formation along the southern side. Consequently, the names Chilapa Formation and Yolomécatl Formation appear to have been applied to the same unit, but in different subbasins. As a result, Yolomécatl Formation was a junior synonym of Chilapa Formation. Therefore and in conformance with Jiménez-Hidalgo et al. (2019, p. 189) and previous geologic mapping by Santamaría-Díaz et al. (2008, fig. 2), the fossil-bearing Yolomécatl Formation of Ferrusquía-Villafranca et al. (2016, p. 198) in the Yolomécatl Subbasin and its immediate vicinity is returned herein to the Chilapa Formation (Appendix A) (see above). Accordingly, Yolomécatl Formation is abandoned in favor of Chilapa Formation on the basis of priority, as prescribed by the NACSN (2005, p. 1565, article 20, remark a). Respective strata in the Yolomécatl Subbasin represent a marginal facies of the dominantly lacustrine Chilapa Formation north of the subbasin (Rodríguez-Caballero, 2019). Lithostratigraphic descriptions of the Chilapa Formation in the Yolomécatl Subbasin and the region to the north are presented below.

4.2. Statuses of Cañada María and San Marcos Andesites, Nicananduta "Group," and Tayata Pyroepiclastics

4.2.1. Abandonment of Cañada María Andesite

Santamaría-Díaz et al. (2008, p. 500, table 1, figs. 2–3) introduced the name Cañada María Andesite for a 400-m-thick volcanic sequence that crops out in an extensive area of western Oaxaca. The andesite overlies the Yanhuitlán Formation and interfingered with the Chilapa Formation. The unit presumably was based on rocks exposed around Cañada María, which lies approximately 9.5 km west of the Yolomécatl Subbasin. However, the Cañada María Andesite was never formally described, and no stratotype was ever specified. Ferrusquía-Villafranca et al. (2016, pp. 197, 200–201, figs. 2–4, table B.1) subsequently described and mapped several new volcanic units (i.e., Nduayaco, Nundichi, and Nicananduta "Groups") that previously had been mapped as the Cañada María Andesite, with the Nicananduta "Group" underlying Cañada María and vicinity (Appendix A). In doing so, they effectively abandoned Cañada María Andesite in favor of Nicananduta "Group." For those reasons, Cañada María Andesite is regarded herein as an abandoned name.

4.2.2. Abandonment of Nicananduta "Group"

Ferrusquía-Villafranca et al. (2016, p. 201, Figs. 3–4) based the Nicananduta "Group" on volcanic rocks surrounding San Sebastian Nicananduta, which lies about 6.2 km north-northwest of Cañada María and 13.5 km west-northwest of the northwestern corner of the Yolomécatl Subbasin. The stratotype was situated west of San Marcos Monte de León, which lies less than 3.0 km northwest of San Sebastian Nicananduta. The Nicananduta "Group" consisted of lava flows and autobreccias of dominantly andesitic composition and was thought to interfinger with the Chilapa Formation (Ferrusquía-Villafranca et al., 2016, p. 201, fig. 4; 2018a, p. 145, fig. 3; 2018b, p. 2, Fig. 3). However, in the area surrounding Guadalupe Vista Hermosa, which lies approximately 4.0 km north-northwest of the northwestern corner of the Yolomécatl Subbasin, the same exposures mapped as the Nicananduta "Group" by those authors and Ferrusquía-Villafranca et al. (2018c, fig. 1) were previously described and mapped as the San Marcos Andesite by Ferrusquía-Villafranca (1976, p. 62, plate 14). That unit also interfingered with the Chilapa Formation. According to Ferrusquía-Villafranca et al. (2016, p. 202), the composition and stratigraphic relations of the Nicananduta "Group" were comparable to those of the San Marcos Andesite. Because both names were applied to the same exposures of the rock unit, Nicananduta "Group" is regarded herein as a junior synonym; therefore, it is abandoned and replaced by San Marcos Andesite in accordance with the NACSN (2005, p. 1565, article 20, remark a) (Appendix A).

The small outlier of volcanic rocks situated at the northwestern corner of the Yolomécatl Subbasin was identified and mapped as the Nicananduta "Group" by Ferrusquía-Villafranca et al. (2016, p. 200, fig. 3; 2018a, fig. 2a; 2018b, fig. 2; 2018c, fig. 1). It probably represents a tongue of the San Marcos Andesite that (1) caps the Chilapa Formation or, relying on dominantly southeasterly dips of 9–25° compiled for the Yolomécatl Formation in the subbasin by Ferrusquía-Villafranca et al. (2018a, fig. 2a), (2) is interbedded with the Chilapa Formation at a level possibly situated above the fossiliferous interval, which is exposed in the outskirts of Santiago Yolomécatl 2.25 km to the southeast.

4.2.3. Statuses of Tayata Pyroepiclastics and Yanhuitlán Formation

Ferrusquía-Villafranca (1976, plate 14) mapped extensive exposures of the Eocene Yanhuitlán Formation in the northern and eastern parts of his study area (i.e., immediately to well north of Yolomécatl Subbasin), mainly north and east of the north-northwesterly plunging anticline (= Teposcolula Anticline [= Anticlinal Teposcolula] of Santamaría-Díaz et al., 2008, p. 496, fig. 2 = Anticlinal Cerro Negro [= Black Hill Anticline] of Márquez-Pérez et al., 2020). As so mapped, the anticline involves the early and late Cretaceous (Aptian or Albian to Cenomanian or Coniacian) marine Teposcolula Limestone Formation and is expressed topographically as a north-south-trending massif or mountain range. However, he also mapped several smaller exposures of the Yanhuitlán Formation west of the anticline. The westernmost outcrop straddled the western boundary of his map area and lies approximately 26.3 km northwest of Santiago Yolomécatl and 9.9 km west-northwest of Villa de Tamazulapam del Progreso. Additional outcrops forming a narrow, rather continuous belt paralleling the western side of the Teposcolula Anticline were mapped between Villa de Tamazulapam del Progreso and San Miguel Tixá to the south-southeast. Santamaría-Díaz et al. (2008, pp. 499–500, figs. 2–3) identified and mapped the Yanhuitlán Formation on both sides of the Teposcolula Anticline as well, but also identified additional outcrops extending far south of the Yolomécatl Subbasin (i.e., west of anticline) and well beyond the area mapped by Ferrusquía-Villafranca (1976, plate 14).

Ferrusquía-Villafranca et al. (2016, p. 200, table B.1) based the Tayata Pyroepiclastics on a brick red, rhythmically bedded, largely fine-grained, clastic sequence that cropped out in the area west to south of the Yolomécatl Subbasin and was previously identified as the Yanhuitlán Formation by Santamaría-Díaz et al. (2008, figs. 2–3). Although the lower contact of the unit was not exposed, the upper contact with the Nundichi "Group" was a paraunconformity. Ferrusquía-Villafranca et al. (2016, p. 200) noted (1) that the Yanhuitlán Formation lies in a basin located east of the massif formed by the Teposcolula Limestone Formation (i.e., Teposcolula Anticline), (2) that mapping of the Yanhuitlán Formation by Santamaría-Díaz et al. (2008, figs. 2–3) west of the anticline implied incorrectly that the formation's depositional basin extended into that area, and (3) that the Tayata Pyroepiclastics, which reportedly resembled the Yolomécatl Formation in general appearance and perhaps were coeval with it, had a depositional basin lying west of that for the Yanhuitlán Formation and separated from it by the Teposcolula Anticline. Presumably because the respective depositional basins were situated on opposite sides of the existing Teposcolula Anticline, Ferrusquía-Villafranca et al. (2016, p. 200, table B.1) proposed the Tayata Pyroepiclastics as an informal unit of formational rank for strata previously assigned to the Yanhuitlán Formation by Santamaría-Díaz et al. (2008, pp. 499–500, figs. 2–3) but lying just west of the anticline.

Based on observations made during our field surveys, it is concluded herein that strata identified as the Tayata Pyroepiclastics by Ferrusquía-Villafranca et al. (2016, fig. 3) are, in fact, part of the Yanhuitlán Formation (Appendix A). Critically, lithologic and mineralogical descriptions of the Yanhuitlán Formation provided by Ferrusquía-Villafranca (1976, pp. 34–35) are remarkably similar to those for the Tayata Pyroepiclastics supplied Ferrusquía-Villafranca et al. (2016, p. 200). Although the latter authors pointed out that the Tayata Pyroepiclastics resembled the Yolomécatl Formation (= Chilapa Formation, see above) in general appearance, the Tayata Pyroepiclastics were found during recent field surveys to be most similar to the Yanhuitlán Formation and not to the marginal facies of the dominantly lacustrine Chilapa Formation. Thus, the names Yanhuitlán Formation and Tayata Pyroepiclastics had been applied to the same sequence exposed in the Santa Cruz Tayata-Santa Catalina Tayata area. As a result, Tayata Pyroepiclastics was a junior synonym of Yanhuitlán Formation (Appendix A). Therefore, strata assigned to the Tayata Pyroepiclastics of Ferrusquía-Villafranca et al. (2016, p. 200) in the Santa Cruz Tayata-Santa Catalina Tayata area are returned herein to the Yanhuitlán Formation. Accordingly, Tayata Pyroepiclastics is abandoned in favor of Yanhuitlán Formation on the basis of priority, as prescribed by the NACSN (2005, p. 1565, article 20, remark a) and in accordance with mapping by Santamaría-Díaz et al. (2008, figs. 2–3).

4.2.4. Summary

Stratigraphic relations discussed earlier in this section indicate that middle to late and late Eocene (or middle) parts of stratigraphic columnar sections compiled by Ferrusquía-Villafranca et al. (2016, fig. 4; 2018a and 2018b, fig. 3) and including the Yolomécatl Formation were mistakenly repeated as Oligocene and early late Oligocene (or upper) portions of the respective sections that contained the Chilapa Formation. Consequently, the stratigraphic relations of other units first recognized by Ferrusquía-Villafranca et al. (2016, pp. 197, 200–201, figs. 3–4) must be considered with respect to (1) the Chilapa Formation, (2) the Yucudaac Andesite, which underlies and interfingers with the Chilapa Formation, and (3) the San Marcos Andesite, which also interfingers with the Chilapa Formation (see above) (Appendix A). Units needing reevaluation include (1) the Nduayaco "Group," which, like the Yucudaac Andesite, now underlies the San Marcos Andesite and the Chilapa Formation, and (2) the Nundichi "Group," which now unconformably underlies the Yucudaac Andesite (see above). Those two names are retained only tentatively herein pending further investigation. Additional research might demonstrate that one or more of the names represent junior synonyms requiring abandonment.

4.3. Tlaxiaxo Formation

Thinly bedded to medium-bedded layers of marl with interbedded layers of dark gray limestone are exposed approximately 4.65 km south of Santiago Yolomécatl. They were observed during field surveys conducted in support of the current investigation in the area surrounding Totonondo, a small community in the northeastern outskirts of San Martín Huamelulpam (Figs. 1 and 3). The strata were identified and mapped as the Cañada María Andesite by Santamaría-Díaz et al. (2008, p. 500, figs. 2–3), but were subsequently mapped as the Nduayaco "Group" by Ferrusquía-Villafranca et al. (2016, p. 195, fig. 3). In contrast, the beds were identified, instead, as the early Cretaceous (Berriasian to Aptian) marine Tlaxiaco Formation by the Servicio Geológico Mexicano, 2010 and Márquez-Pérez et al. (2020) (Appendix A).

4.4. Lithostratigraphy of Chilapa Formation

4.4.1. Chilapa Formation of Yolomécatl Subbasin—subdivisions, thicknesses, generalized lithostratigraphy, and fossil occurrences

Ferrusquia-Villafranca (1976, p. 67) based the Chilapa Formation on strata exposed in the area partly surrounding Villa de Chilapa de Díaz in northwestern Oaxaca (Fig. 3). It represents an early Oligocene, mostly lacustrine sequence in the Tlaxiaco Basin. As mapped by Santamaría-Díaz et al. (2008, Fig. 2), exposures of the formation in the Yolomécatl Subbasin and its immediate vicinity represented a southern outlier of the unit. There, the Chilapa Formation, later referred to locally as the Yolomécatl unit or Yolomécatl Formation by Jiménez-Hidalgo et al. (2015, p. 40, Fig. 2) and Ferrusquía-Villafranca et al. (2016, p. 198, Fig. 4), respectively, was around 240 or 250 m thick. On the other hand, Ferrusquía-Villafranca et al. (2018a, p. 144, Fig. 3, see Figs. 4–5; 2018b, p. 2, Fig. 3; 2018c, p. 204) indicated that the formation was roughly 650 m in thickness, but (2018a, p. 144) reported that only about 250 m of continuous section could be measured. However, recent field investigations conducted in support of this study indicated the formation was about 325 m thick (Fig. 2).

In the Yolomécatl Subbasin, the Chilapa Formation comprises two stratigraphically superposed units. The Iniyoo LF consists mostly of

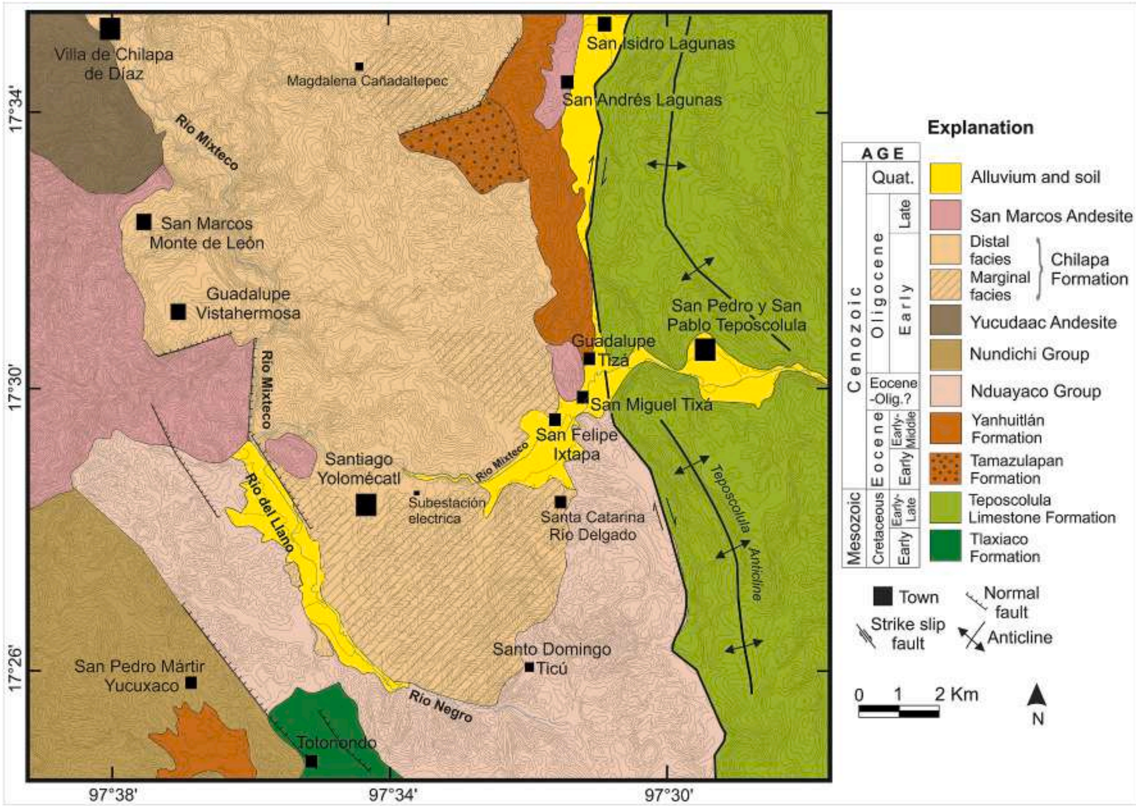

Fig. 3. Geologic map of Villa de Chilapa de Diaz-Santiago Yolomécatl area, including Yolomécatl Subbasin. Contour interval = 20 m. Geographic names after INEGI 2001a, 2001b.

extinct land mammal species represented by remains from the red silty mudstone interval or upper unit (Fig. 2).

4.4.1.1. Lower unit. The lower part of the Chilapa Formation in the Yolomécatl Subbasin was initially reported to be around 40 m thick by Jiménez-Hidalgo et al. (2015, p. 40), but recent field surveys indicated the lower unit (= "lower beds" of Guerrero-Arenas et al., 2020, p. 2) was around 65 m in thickness, as indicated by Guerrero-Arenas et al. (2020, fig. 2). The lower unit consisted of alternating layers of red mudstone with some lithovolcanic fragments, greenish to grayish volcanic sandstone, volcarenitic matrix-supported conglomerate, greenish and whitish siltstone, and thickly to very thickly bedded, partially silicified limestone (Fig. 2) (Jiménez-Hidalgo et al., 2015, p. 40; 2018a, p. 428; 2019, p. 189).

4.4.1.2. Upper unit or red silty mudstone interval. The vertebrate fossil-bearing upper unit or red silty clay interval of the Chilapa Formation in the Yolomécatl Subbasin was originally reported to be around 200 m thick by Jiménez-Hidalgo et al. (2015, p. 40), but later (2018a, p. 428) was stated to be about 250 m in thickness. However, recent field surveys indicate the upper unit (= "middle beds" and "upper beds" of Guerrero-Arenas et al., 2020, p. 2) is approximately 260 m in thickness, as indicated by Guerrero-Arenas et al. (2020, Fig. 2). It conformably overlies the lower unit. According to Jiménez-Hidalgo et al. (2015, p. 40; 2018a, p. 428; 2019, p. 189), Guerrero-Arenas et al. (2020, p. 2, Fig. 2), and Ortiz-Caballero et al. (2020, p. 1192), the red silty mudstone interval or upper unit comprises (1) layers of thinly to thickly bedded, reddish mudstone interbedded with (2) several paleosols, layers of sandstone, chert, silcrete or silicified calcrete, occasional tuff beds, and (3) lenses or beds of volcanic and limestone pebble, cobble and boulder conglomerate (Fig. 2). Ferrusquía-Villafranca et al. (2016, p. 198; 2018a, p. 144, Figs. 4–5) provided similar lithostratigraphic descriptions of the Yolomécatl Formation (= Chilapa Formation; see above).

4.4.1.3. Fossil land mammal occurrences in upper unit. IGM specimens from the Yolomécatl Subbasin and representing taxa constituting the Iniyoo LF were found in a massive, "moderately" fossiliferous, 1.59-m-thick bed (unit 20 of Ferrusquía-Villafranca et al., 2018a, fig. 4, table 1) comprising red friable siltstone and fine-grained sandstone previously assigned to the Yolomécatl Formation. However, two of the fossil localities were reported to lie 6 m apart stratigraphically by Ferrusquía-Villafranca et al. (2018b, p. 7). UMPE specimens were found in fossil-bearing layers resembling those in the Chilapa Formation exposed north of the subbasin and consisting of reddish silty claystone with some lithovolcanic fragments and pedogenic alteration (Jiménez-Hidalgo et al., 2018a, p. 428; 2019, p. 189). The fossil-bearing beds were reported to span about 40 m by Jiménez-Hidalgo et al. (2018a, p. 428) and to lie in the middle and around 100 m below the top of the upper unit or red silty mudstone interval of the Chilapa Formation. However, recent field investigations undertaken as part of the current study have determined that the vertebrate fossil-bearing beds span nearly 88.5 m and lie at least 5.2 m above the base of the upper unit. Eight layers containing fossilized bones and teeth of land mammals have now been documented in the fossil-bearing interval (Fig. 2). As illustrated by Guerrero-Arenas et al. (2020, Fig. 2), three of those layers occurred in the lower part of the "middle beds" (i.e., in lowermost part of lower unit) and four in the lower part of the "upper beds" (i.e., near middle of upper unit). Textural, mineralogical, and infrared analyses also conducted for this study indicated that the beds were lithologically similar to those found in the Chilapa Formation north of the Yolomécatl Subbasin and, thus, belonged to that formation, a conclusion supported by similarities of stratigraphic relations, as well (Jiménez-Hidalgo et al., 2018b; 2019, p. 189; Rodríguez-Caballero, 2019; Guerrero-Arenas et al., 2020, p. 2; Ortiz-Caballero et al., 2020, p. 1191) (Fig. 3). Despite being separated by a 6-m-thick stratigraphic interval, the two IGM specimens representing the sciurid *Douglassciurus oaxacaensis* and the zetamyid *Protozetamys mixtecus* were reportedly found about 55 m approximately the Ar/Ar-dated tuff sheet (Ferrusquía-Villafranca et al., 2018b, pp. 2, 7). Both specimens were presumably from unit 20 of Ferrusquía-Villafranca et al. (2018a, Fig. 4, table 1), 52.8 m above the dated silicified tuff sheet (= their unit 1) and in the interval that produced the UMPE specimens.

4.4.2. Lithostratigraphic descriptions and comparison of Chilapa Formation in Yolomécatl Subbasin and region to north

As originally described by Ferrusquía-Villafranca (1976, p. 67) and later reported by the (Servicio Geológico Mexicano, 2011), the Chilapa Formation consisted of sandstone, siltstone, and silicified lacustrine limestone beds that were (1) generally cream colored (i.e., pale yellow), but also ranging to white, gray, ocher (poorly defined, but usually includes yellow to red or brown), brown, and pale green, (2) thin to medium bedded (i.e., 0.5–60.0 cm thick), but occasionally thickly and massively bedded (i.e., 3.0–4.0 m thick), and (3) poorly to well indurated. Sandstone and siltstone beds consisted of volcarenitic and occasionally contained gypsum veinlets and peat lenses. The stratotype was situated in the area immediately surrounding Villa de Chilapa de Díaz, which lies approximately 16.5 km west-northwest of the northwestern corner of the Yolomécatl Subbasin (Fig. 1). According to Petróleos Mexicanos (Petróleos Mexicanos, 1988), the silicified limestone beds in the Chilapa Formation were cream colored or whitish, 5–80 or 100 cm thick, and contained gastropod, bivalve, ostracod, and filamentous algal remains. Interbedded with the siliceous limestone layers were beds of gray chert and yellowish and greenish sandstone, siltstone, and tuffaceous claystone. The base of the formation interfingered with andesitic rocks.

Similar fluviolacustrine strata to the south in the Yolomécatl Subbasin and its immediate vicinity were identified and mapped as the Yolomécatl Formation by Ferrusquía-Villafranca et al. (2016, fig. 3; 2018a, fig. 2a; 2018b, fig. 2; 2018c, fig. 1) and Ferrusquía-Villafranca and Wang (2021, p. 2, fig. 2). However and based on results of field surveys conducted in support of this investigation, the Yolomécatl Formation was reassigned to the Chilapa Formation by Jiménez-Hidalgo et al. (2018b; 2019, p. 189), Rodríguez-Caballero (2019), Guerrero-Arenas et al. (2020, p. 2), and Ortiz-Caballero et al. (2020, p. 1191). In the area surrounding Cerro Yucuyóo and along the Río Mixteco, about 1.0 km northeast of Santiago Yolomécatl or near the northern border of the Yolomécatl Subbasin, the Chilapa Formation consists of alternating cream-colored volcarenitic beds that are overlain by layers of greenish to whitish siltstone, sandstone, and some matrix-supported conglomerate that, in turn, are overlain by silicified limestone and red mudstone beds (Figs. 1, 3 and 4). The same stratigraphic succession occurs in the area surrounding the Subestación eléctrica, which is situated around 2.0 km east of Santiago Yolomécatl or near the northeastern corner of the Yolomécatl Subbasin (Figs. 1, 3 and 4). A similar sequence was found in the exposure lying immediately northeast of the Río Mixteco and extending nearly 9.0 km in a dominantly northerly direction from a point approximately 2.0 km east of the northeastern corner of the Yolomécatl Subbasin in the San Felipe Ixtapa-San Miguel Tixá area to one a bit less than 2.0 km northeast of Magdalena Cañadaltepec (Figs. 1, 3–5). There, the Chilapa Formation consists of interbedded layers of volcanic conglomerate, cream-colored volcarenitic sandstone, red mudstone, greenish and reddish siltstone, claystone, calcrete, and silicified lacustrine limestone. Some of the red mudstone layers represented red beds or paleosols exhibiting pedogenic alteration (Fig. 5).

Critically, recent field investigations demonstrated that strata exposed along the northern margin of the Yolomécatl Subbasin northeast of Santiago Yolomécatl and previously identified and mapped as the Yolomécatl Formation by Ferrusquía-Villafranca et al. (2016, fig. 3; 2018a, fig. 2a; 2018b, fig. 2; 2018c, fig. 1) were traceable across the Río Mixteco and north of the subbasin into the adjacent area west-southwest of San Felipe Ixtapa (Figs. 3–5), where laterally equivalent beds of limestone, calcrete, claystone, siltstone, sandstone, and conglomerate were mapped by those authors as the Chilapa Formation. Exposures for the two units were continuous with those containing their respective stratotypes. For those reasons, Jiménez-Hidalgo et al. (2018b, 2019, p. 189), Rodríguez-Caballero (2019), Guerrero-Arenas et al. (2020, p. 2), and Ortiz-Caballero et al. (2020, p. 1191) assigned the fossil-bearing beds in the Yolomécatl Subbasin to the Chilapa Formation (Appendix A). In doing so, they effectively abandoned Yolomécatl Formation in favor of Chilapa Formation. Replacement of Yolomécatl Formation was supported on the bases of synonymy and priority, as discussed above.

5. U–Pb zircon geochronology of Chilapa Formation

Jiménez-Hidalgo et al. (2018b; 2019, pp. 188–189), Guerrero-Arenas et al. (2020, p.2, fig. 2), and Ortiz-Caballero et al. (2020, p. 1192) reported a U–Pb maximum depositional age of 30.6 Ma for detrital zircon grains from a conglomeratic sandstone layer that lies in the fossil-bearing interval of the upper unit of the Chilapa Formation in the Yolomécatl Subbasin at 17° 27′ 24″ North Latitude and 97° 34′ 36″ West Longitude. That bed, about 1.0 m thick, lies approximately 23.8 m above the base of the upper unit (i.e., near middle of "middle beds" of Guerrero-Arenas et al., 2020, p.2, fig. 2) (Fig. 2).

As part of this ongoing investigation and to further corroborate the early Oligocene age of the fossiliferous strata, a second sample was collected from a bed higher in the upper unit of the Chilapa Formation in the Yolomécatl Subbasin at 17° 26′ 50 ″ North Latitude and 97° 34′ 22.3″ West Longitude. It was then analyzed to estimate the layer's maximum depositional age. The new sample was collected from a 1.15-m-thick sandstone bed that lies approximately 9.2 m above the eighth or uppermost fossil vertebrate-bearing layer, about 115 m above the previously dated, conglomeratic sandstone bed, and roughly 140 m above the base of the formation's upper unit (Fig. 2). Sample preparation followed currently accepted techniques described by Solari et al. (2007, p. 1272). U–Pb radiometric dating analyses were carried out at the Laboratorio de Estudios Isotópicos at the Centro de Geociencias of the Universidad Nacional Autónoma de México using a Thermo Scientific iCap Qc Inductively Coupled Plasma-Mass Spectrometry system coupled to a Resonetics - RESOlution M-50 excimer laser workstation. Concordant U–Pb age data resulted from analyses of 27 detrital zircon crystals. To estimate their mean maximum depositional age, zircon age data were log-transformed, analyzed with the Minimum Mixture Model in DensityPlotter software, and plotted with the Kernel Density Estimator in the same program (Vermeesch, 2012, p. 193).

The newly dated sandstone bed from approximately 9.2 m above the fossil vertebrate-bearing interval is 30.62 ± 0.67 Ma in age, based on U–Pb dating analysis of detrital zircon crystals (Fig. 6). That date is entirely consistent with the previously reported and similarly derived U–Pb age of 30.6 Ma for the conglomeratic sandstone layer lying about 115 m lower in the section (i.e., in fossil-bearing interval of Chilapa Formation's upper unit). Both dates, in turn, are fully compatible with (1) early Oligocene and earliest Arikareean or Ar1 age assignments for the formation's upper unit and the Iniyoo LF (see below) and (2) the Pb-alpha date of 49.0 ± 8.0 Ma for zircon crystals from a tuff sheet in the underlying Yanhuitlán Formation (see above).

6. Revised K–Ar and Ar/Ar geochronology of volcanic units bracketing Chilapa Formation

Unfortunately, no K–Ar or Ar/Ar radiometric age determination is available for the Chilapa Formation or the Nduayaco "Group," which unconformably underlies the formation in the Yolomécatl Subbasin and its immediate vicinity. In contrast, radiometric dating analyses have provided K–Ar and Ar/Ar dates for (1) the Llano de Lobos Tuff, which conformably overlies the Yanhuitlán Formation north of the subbasin, (2) the Yucudaac Andesite's lowermost flow or lower tongue, which

Fig. 4. A. Typical silicified limestone and greenish sand and silt beds of lower unit of Chilapa Formation at Cerro Yucuyóo in Yolomécatl Subbasin. B. Silicified limestone bed in lower unit of Chilapa Formation in area surrounding Subestación eléctrica in Yolomécatl Subbasin. C. Red silty mudstone interval or upper unit of Chilapa Formation's marginal facies in area surrounding San Felipe Ixtapa. D. Silicified limestone bed in red silty mudstone interval or upper unit of Chilapa Formation's marginal facies in area surrounding San Felipe Ixtapa.

Fig. 5. A, B. Red silty mudstone interval or upper unit of Chilapa Formation's marginal facies in area surrounding Magdalena Cañadaltepec. C. Typical appearance of upper unit of Chilapa Formation's marginal facies in Yolomécatl Subbasin.

unconformably overlies the Llano de Lobos Tuff north of the subbasin and underlies the Chilapa Formation, and (3) the San Marcos Andesite (= Nicananduta "Group"; see above), which overlies the Chilapa Formation in the Yolomécatl Subbasin and interfingers with it to the north (Appendix B).

Ferrusquía-Villafranca et al. (1974, pp. 257–258, table 2; 2016, p. 201, table B.4, p. 223) and Ferrusquía-Villafranca (1976, p. 61, table 7) reported uncorrected K–Ar ages of 28.2 ± 0.6 and 29.6 ± 0.6 Ma with a mean age of 28.9 Ma for their sample fractions FV69-182 (roca completa = whole rock) and FV69-182 from the lowermost flow or lower tongue of the Yucudaac Andesite at Cerro Yucudaac (Appendix B). The dated sample presumably was recovered from a stratigraphic level laterally equivalent to one below the Chilapa Formation. The two dates are revised herein as 28.939 ± 0.6 and 30.376 ± 0.6 using the correction factor of 1.0262 prescribed by Dalrymple (1979, table 2) (see above) (Appendix B). Therefore, the Chilapa Formation is probably no older than about 28.94 or 30.38 Ma in age.

Uncorrected Ar/Ar ages of 30.0 ± 0.8 and 31.6 ± 1.0 Ma for the Llano de Lobos Tuff, which underlies the Yucudaac Andesite, were reported by Cerca et al. (2007, p. 16, table 1) for their samples TAM-1 (all) and TAM-5 (all), respectively. Both determinations are entirely consistent with those for the overlying Yucudaac Andesite (see above) (Appendix B).

On the other hand, Ferrusquía-Villafranca et al. (2016, p. 201, table

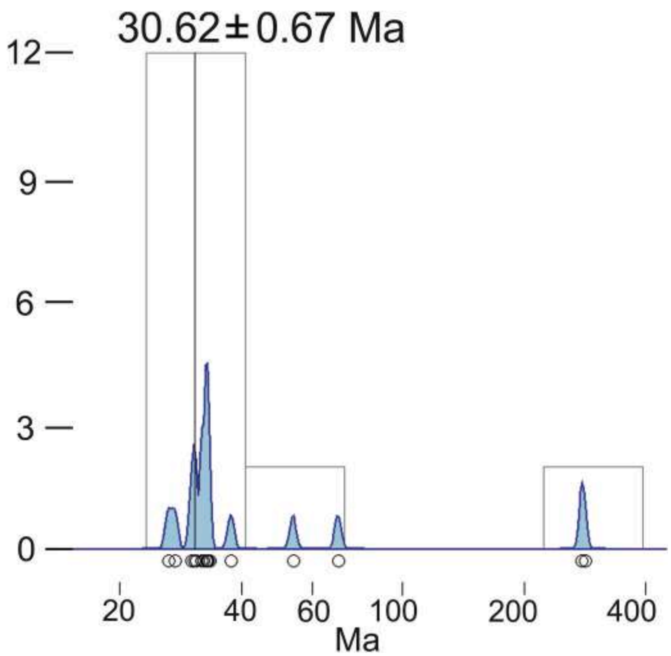

Fig. 6. Maximum depositional age of sandstone bed lying approximately 9.2 m above eighth or highest fossil vertebrate-bearing bed of fossiliferous sequence in red silty mudstone interval or upper unit of Chilapa Formation in Yolomécatl Subbasin, based on U–Pb detrital zircon geochronology.

B.4, p. 221, sample FV14-174, fig. C1) reported an uncorrected Ar/Ar date of 27.7 ± 0.7 (or 27.65 ± 0.71) Ma on biotite from the San Marcos Andesite (= Nicananduta "Group"), which overlies the Yolomécatl Formation (= Chilapa Formation) at the northwestern corner of the Yolomécatl Subbasin. That date was generated by Ar/Ar analysis using GA-1550 biotite crystals as the fluence monitor and the corresponding, previously recognized Ar/Ar age of 98.79 ± 0.54 Ma (see above). However, the date for the San Marcos Andesite is recalculated in this report as 27.829 ± 0.716 Ma using the previously recommended and intercalibrated age of 28.02 ± 0.16 Ma for FCTs and *ArArRecalc 7/31/09* (see above) (Appendix B). Consequently, the Chilapa Formation is probably no younger than approximately 27.83 Ma in age.

In summary, the geochron of the Chilapa Formation is probably between 27.83 and 28.94 Ma and later early Oligocene in age. The age of the geochron appears consistent with early Oligocene, U–Pb maximum depositional ages of 30.6 ± 0.77 and 30.62 ± 0.67 Ma for detrital zircon grains from sandstone beds lying about 18.5 m and 9.2 m, respectively, above the bottom and top of the nearly 88.4-m-thick vertebrate fossil-bearing interval of the Chilapa Formation in the Yolomécatl Subbasin (Fig. 2, Appendix B).

The K–Ar age of 35.7 ± 1.0 Ma (Santamaría-Díaz et al., 2008, p. 500, table 1, figs. 2–3) was for their sample AS-03 matrix (= whole rock) (Appendix B), then thought to be from the Cañada María Andesite. However, Ferrusquía-Villafranca et al. (2016, p. 201) later determined the dated unit was actually the Yucudaac Andesite, based on geographic coordinates provided by Santamaría-Díaz et al. (2008, table 1) for the respective sampling site. They considered the date of 35.7 ± 1.0 Ma incompatible with the two uncorrected K–Ar ages of 28.2 ± 0.6 and 29.6 ± 0.6 Ma and the mean age of 28.9 Ma for the lowermost flow or lower tongue of the Yucudaac Andesite (Appendix B). Consequently, the date of 35.7 ± 1.0 Ma, which relied on whole-rock analysis (Ferrusquía-Villafranca and Ruiz-González, 2015, table 1, p. 326), is considered unreliable (i.e., too old) and, thus, is rejected herein. The dated sample probably contained detrital grains reworked from older volcanic rocks.

Ferrusquía-Villafranca et al. (2016, p. 200, table B.4, sample FV14-204) reported an uncorrected Ar/Ar date of 40.3 ± 1.0 Ma for a silicic or silicified tuff sheet in the Yolomécatl (= Chilapa) Formation of the Yolomécatl Subbasin. As above, that date is recalculated herein as 40.561 ± 1.009 Ma to correct for ages originally generated by Ar/Ar dating analyses using GS-1550 biotite crystals as the fluence monitor and the corresponding, previously accepted date of 98.79 ± 0.54 Ma.

According to Ferrusquía-Villafranca et al. (2018b, pp. 2, 7) and Ferrusquía-Villafranca and Wang (2021, p. 4), some fossil land mammal remains representing taxa occurring in the Yolomécatl (= Iniyoo) LF were found about 55 m and/or 55–65 m, respectively, above the dated tuff sheet. That bed is presumed herein to be the 0.53-m-thick silicified tuff sheet (= bed 1) shown lying at the base of the Yolomécatl Formation's stratotype and 52.8 m below the 1.59-m-thick fossil-bearing layer (= bed 20) by Ferrusquía-Villafranca et al. (2018a, Fig. 4, see table 1). However, a corrected age of 40.561 ± 1.009 Ma for any dated bed in the Chilapa Formation is regarded herein as much too old relative to (1) U–Pb maximum depositional ages of 30.6 ± 0.77 and 30.62 ± 0.67 Ma for sandstone layers occurring about 18.5 m and 9.2 m above the bottom and top, respectively, of the nearly 88.4-m-thick vertebrate fossil-bearing interval in the local upper unit of the Chilapa Formation, (2) a corrected Ar/Ar date of 27.829 ± 0.716 Ma for the bracketing and interfingering San Marcos Andesite (= Nicananduta "Group"), which overlies the Chilapa Formation in the Yolomécatl Subbasin, (3) corrected K–Ar ages of 28.939 ± 0.6 and 30.376 ± 0.6 Ma for the Yucudaac Andesite's lowermost flow or lower tongue, which underlies the Chilapa Formation north of the subbasin, and (4) an uncorrected Ar/Ar age of 30.0 ± 0.8 Ma for the Llano de Lobos Tuff, which was successively overlain by the Cerro Verde Tuff and the lowermost flow of the Yucudaac Andesite (Appendix B).

Moreover, a field survey that was conducted for the present study and used geographic coordinates provided by Ferrusquía-Villafranca et al. (2016, table B.4) for their sample FV14-204 did not find a tuff sheet at the presumed location, or the immediate vicinity, of the sampling site specified by the coordinates. Instead, only mudstone beds were found at that site. On the other hand, the probable location of the sampling site ("La Cascadita" outcrop) was subsequently found nearby, approximately 1.5 km south of Santiago Yolomécatl. Ferrusquía-Villafranca et al. (2018a, fig. 11) showed the "La Cascadita" outcrop with two superposed layers the authors identified as tuff sheets, which were interbedded with layers of conglomerate. Critically, an inspection of the tuff sheets during the field survey revealed they were actually sandstone beds. Sample FV14-204 was probably collected from one of those layers, and the K-feldspar crystals subjected to radiometric dating analysis likely represented volcanic debris reworked from a substantially older unit. In addition, those two sandstone beds were found to be bracketed by the two other sandstone beds occurring in the Chilapa Formation's upper unit and determined to be 30.6 ± 0.77 Ma and 30.62 ± 0.67 Ma old on the basis of U–Pb dating analyses. Those two dates represent maximum depositional ages (see above). The first two beds are estimated to lie 18 m above the lower of the latter two beds that was dated at 30.6 ± 0.77 Ma in age and lies near the middle of the "middle beds" of the upper unit (see Guerrero-Arenas et al., 2020, fig. 2). For those reasons, the corrected Ar/Ar date of 40.561 ± 1.009 Ma for the silicic (or felsic) tuff sheet in the local upper unit of the Chilapa Formation is considered highly unreliable and, therefore, is rejected herein. Correspondingly, any land mammal age assignment relying on that date is also regarded in this report as erroneous. Moreover, the dated sample from the tuff sheet consisted of glass shards (Ferrusquía-Villafranca and Wang, 2021, p. 4), analysis of which can result in anomalously old apparent ages because of ^{39}argon loss by recoil (McDougall and Harrison, 1999).

The Nundichi "Group," which unconformably underlies the San Marcos Andesite (= Nicananduta "Group") west of the Yolomécatl Subbasin, was determined to be 32.9 ± 0.9 Ma old on the basis of K–Ar dating analysis (Martiny et al., 2000, p. 81, Fig. 5, table 1, sample CON-101; Ferrusquía-Villafranca et al., 2016, p. 201, figs. 3–4, table B.1, p. 221 and table B.4, simple CON-101) (Appendix B). Such an age is consistent with a corrected Ar/Ar date of 27.829 ± 0.716 Ma for the San Marcos Andesite and U–Pb maximum depositional ages of 30.6 ± 0.77

and 30.62 ± 0.67 Ma for the Chilapa Formation (see above).

7. Current biochronology and correlation of Iniyoo Local Fauna

Jiménez-Hidalgo et al. (2015, p. 46) regarded the Iniyoo LF as middle to late Chadronian (Ch2–Ch4) and late Eocene or Priabonian in age (Jiménez-Hidalgo and Guerrero-Arenas, 2015, p. 19). Their age assignment was based on the presence in the assemblage of the equid *Miohippus assiniboiensis*, which had been reported earlier from local faunas of middle to late Chadronian age by Prothero and Shubin (1989, p. 164). However, *M. assiniboiensis* was later considered similar in occlusal anatomy and degree of hypsodonty to several Whitneyan and early Arikareean species of the genus (i.e., *M. equiceps*, *M. gidleyi*, and *M. validus*) by Storer and Bryant (1993, p. 663). Therefore, it was regarded as a likely junior synonym of at least one of the other species. Consequently and contrary to Jiménez-Hidalgo et al. (2018a, p. 428), *M. assiniboiensis* is not a Chadronian index species. Instead, the occurrence of that species represents another taxon supporting early (or earliest) Arikareean (Ar1) and late early Oligocene age assignments for the Iniyoo LF advocated by Jiménez-Hidalgo et al. (2017, 2018b; 2019, p. 189), Guerrero-Arenas et al. (2020, p. 2), and Ortiz-Caballero et al. (2020, p. 1191).

Jiménez-Hidalgo et al. (2017, 2018b; 2019, p. 188) regarded the Iniyoo LF as no older than Arikareean or approximately 30.0 Ma in age. They (2018b; 2019, p. 189) considered the assemblage early (or earliest) Arikareean (Ar1) in age. Its geochronologic or absolute age was further constrained to the interval spanning about 28.0–29.0 Ma ago, based on the FAD of the amphicyonid *Mammacyon* and LADs of the tayassuid *Perchoerus probus* and the rhinocerotid *Subhyracodon* (Jiménez-Hidalgo et al., 2018b).

According to Tedford et al. (2004, figs. 6.2–6.3), Woodburne (2004, fig. 8.6), and Albright et al. (2008, fig. 11), the geochron for the earliest Arikareean (Ar1) NALMA spanned the interval from 28.0 to 30.0 Ma ago. However, that geochron is now approximately 28.0–29.75 Ma and later early Oligocene in age, as illustrated by Speijer et al. (2020, fig. 28.12, p. 1114). They placed the early-late Arikareean (Ar1-Ar2) boundary in Chron C10n.2n (i.e., late early Oligocene Epoch), which spans the interval 28.087–27.859 Ma ago (Ogg, 2012, fig. 5.2, p. 91), instead of Chron C9r (contrary to Woodburne, 2004, fig. 8.6; and Albright et al., 2008, fig. 11). Similarly, those authors located the mutual Rupelian-Chattian and early-late Oligocene boundaries at 27.29 Ma ago, or the beginning of Chron C9n. Coccioni et al. (2018, pp. 27, 29) and Cohen et al. (2013, updated 2020) recently calibrated the boundaries to an astrochronologic age 27.82 Ma (Coccioni et al., 2018, p. 29) earlier Chron C9r. The Chron 10n.1n-C9r boundary is 27.859 Ma in age Ogg (2012, fig. 5.2, pp. 90–91). Consequently, the Iniyoo LF is still entirely later early Oligocene and dominantly if not exclusively later earliest Arikareean (later Ar1) in age, based on (1) the corrected K–Ar age of 28.939 ± 0.6 for the lowermost flow or lower tongue of the Yucudaac Andesite, which underlies the Chilapa Formation north of the Yolomécatl Subbasin, and (2) the revised Ar/Ar date of 27.829 ± 0.716 Ma for the San Marcos Andesite (= Nicananduta "Group"), which overlies the Chilapa Formation at the northwestern corner of the subbasin (see above). Those age determinations suggest the Iniyoo LF is 27.83–28.94 Ma old, a geochron fully compatible with an age span of 28.0–29.75 Ma for the earliest Arikareean (Ar1) geochron. However, if assemblages from the upper part of the "upper beds" in the Chilapa Formation's upper unit were less than 28.0 Ma old, then those assemblages would be earliest late early Arikareean (earliest Ar2) but still later early Oligocene in age.

According to Jiménez-Hidalgo et al. (2019, p. 189), the Iniyoo LF is taxonomically most similar to land mammal assemblages from the middle part of the Turtle Cove Member of the John Day Formation in north-central Oregon and, to a lesser extent, the Upper Sharps Formation of southwestern South Dakota. The geochronologic age of the assemblages from the Turtle Cove Member are constrained by integrated biostratigraphic, radiometric, and magnetostratigraphic data provided by Albright et al. (2008, Figs. 10–11), whereas such an age for those from the Upper Sharps Formation is based only on biostratigraphic and magnetostratigraphic data presented by Tedford et al. (1996, Figs. 6–7, 9). As indicated by Albright et al. (2008, Figs. 10–11), correlative assemblages in the Turtle Cove Member are found between the Blue Basin and Deep Creek Tuffs (i.e., in Units F to J). The two tuff beds have been determined to be ca. 28.8 Ma and 27.89 ± 0.57 Ma in age (uncorrected dates) on the basis of Ar/Ar dating analyses. In the Upper Sharps Formation, correlative assemblages extend upwards from just above the disconformity at the base of the formation (Tedford et al., 1996, Figs. 6–7, 9).

Ongoing studies and future publications will clearly result in a number of taxonomic changes. In some cases, taxa will likely be assigned to other genera or even families. Nevertheless, such revisions are not expected to substantially change the later earliest Arikareean (later Ar1) age assignment for the Iniyoo LF, although the youngest assemblages constituting the local fauna might turn out to be earliest late early Arikareean (earlier Ar2) in age.

8. Conclusions

Recent studies of fossil remains from the Yolomécatl Subbasin and the respective fossil-bearing strata have resulted in the following conclusions.

1. The Iniyoo LF occurs in fluviolacustrine strata previously assigned to the Yanhuitlán and Yolomécatl Formations but now recognized as a marginal facies of the dominantly lacustrine Chilapa Formation, which unconformably overlies volcanic rocks.
2. Consequently, Yolomécatl Formation is abandoned in this report in favor of Chilapa Formation on the bases of synonymy and priority.
3. Similarly, Yolomécatl and Yanhuitlán LFs are rejected in this contribution in favor of Iniyoo LF for the same reasons.
4. The Iniyoo LF, which occurs in the upper unit (= "middle beds" and "upper beds") of the Chilapa Formation, is later earliest Arikareean (later Ar1) (i.e., later early Oligocene) or roughly 28.0–29.0 Ma in age, based on the first appearance datum for the amphicyonid *Mammacyon* and the last appearance datums of the tayassuid *Perchoerus probus* and the rhinocerotid *Subhyracodon.*
5. Such age assignments are also supported and further refined by corrected K–Ar and Ar/Ar dates and U–Pb maximum depositional ages that also constrain the age of the Chilapa Formation. Critical radiometric age determinations include (1) corrected K–Ar dates of 28.939 ± 0.6 and 30.376 ± 0.6 Ma for the Yucudaac Andesite's lowermost flow or lower tongue, which underlies the Chilapa Formation, (2) a revised Ar/Ar date of 27.829 ± 0.716 Ma for the San Marcos Andesite (= Nicananduta "Group"), which overlies the Chilapa Formation in the Yolomécatl Subbasin, and (3) U–Pb ages of 30.6 ± 0.77 and 30.62 ± 0.67 Ma for detrital zircon crystals from sandstone beds in the Chilapa Formation occurring about 18.5 m and 9.2 m, respectively, above the bottom and top of the nearly 88.4-m-thick vertebrate fossil-bearing interval. The K–Ar and Ar/Ar dates suggest the Iniyoo LF and the Chilapa Formation are approximately 27.83–28.94 Ma old. However, if the youngest assemblages constituting the Iniyoo LF from the upper part of the "upper beds" in the Chilapa Formation's upper unit were younger than 28.0 Ma in age, then those assemblages would be earliest late early Arikareean (earliest Ar2) but still later early Oligocene in age.
6. An uncorrected Ar/Ar date of 40.3 ± 1.0 Ma for K-feldspar crystals in sample FV14-204 from a bed first identified as a silicic or silicified tuff sheet (= unit 1) and found lying roughly 55 m below the stratigraphic interval (= unit 20) producing the IGM fossil rodent specimens is rejected herein because no such bed could be found at the location specified by geographic coordinates as the sampling site. However, the probable sampling site with two successive beds identified as tuff sheets was subsequently located at the nearby "La

Cascadita" outcrop. Critically, the beds were found to consist of sandstone. The K-feldspar crystals in sample FV14-204 that were subjected to radiometric dating analysis likely represented reworked volcanic debris. Consequently, the Ar/Ar date and any land mammal age assignment relying on it are considered unreliable.

7. San Marcos Andesite and Nicananduta "Group" were applied to the same exposures of an andesitic unit interfingering with the Chilapa Formation. Accordingly, Nicananduta "Group" is abandoned herein and replaced by San Marcos Andesite on the bases of synonymy and priority.

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Author contributions

EJH, EBL, IIA, NRC, RGA: conceptualization, methodology, and formal analyses. EJH, EBL: report preparation (writing, reviewing, and editing draft and final manuscripts). IIA, RGA: report preparation (writing, preparing, reviewing, and editing specific sections of draft and final manuscripts). EJH: funding acquisition.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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Appendices.

Appendix A

Lithostratigraphic units recognized in Villa de Chilapa de Díaz-Santiago Yolomécatl area of northwestern Oaxaca and units' respective synonyms or previous formational assignments.

Lithostratigraphic Unit (this paper)	Synonym or Previous Formational Assignment	Previous Author
Chilapa Formation	Yanhuitlán Formation unit Ti [cz] (= Huajuapam Formation)	Erben (1956), Jiménez-Hidalgo et al. (2011), Ferrusquía-Villafranca and Ruiz-González (2015), Márquez-Pérez et al. (2020)
	units Ti [lm-ar], Ti [ar-cg] (= Yanhuitlán Formation)	INEGI (1994)
		González-Ramos et al. (2000)
	TpaeCgp-Ar	Jiménez-Hidalgo and Guerrero-Arenas (2015), Jiménez-Hidalgo et al. (2015)
	Yolomécatl unit	Ferrusquía-Villafranca et al. (2016),
	Yolomécatl Formation	Ferrusquía-Villafranca and Wang (2021)
	?Chilapa Formation	Ferrusquía-Villafranca et al. (2016)
San Marcos Andesite	Tom [A]	INEGI (1994)
	Tem [TA-A]	González-Ramos et al. (2000)
	Cañada María Andesite	Santamaría-Díaz et al. (2008)
	Nicananduta "Group"	Ferrusquía-Villafranca et al. (2016),
	ToDa-R	Ferrusquía-Villafranca and Wang (2021)
		Márquez-Pérez et al. (2020)
Yucudaac Andesite	Tom [A]	INEGI (1994)
	Tem [TA-A]	González-Ramos et al. (2000)
	Cañada María Andesite	Santamaría-Díaz et al. (2008)
Nundichi "Group"	Tom [A]	INEGI (1994)
Nduayaco "Group"	Tem [TA-A]	González-Ramos et al. (2000)
	Cañada María Andesite	Santamaría-Díaz et al. (2008), Márquez-Pérez et al. (2020)
Yanhuitlán Formation	Tayata Pyroepiclastics	Ferrusquía-Villafranca et al. (2016)
Tlaxiaco Formation	Cañada María Andesite	Santamaría-Díaz et al. (2008)
	Nduayaco "Group"	Ferrusquía-Villafranca et al. (2016)

Appendix B

Paleogene Pb-alpha, Ar/Ar, K–Ar, and U–Pb dates for units recognized in Villa de Chilapa de Díaz-Santiago Yolomécatl area and vicinity of northwestern Oaxaca, Mexico.

Lithostratigraphic Unit	Original Age (Ma)	Dating Analysis	Reference	Sample	Recalculated Age (Ma) (this study)	Mineral
San Marcos Andesite	27.65 ± 0.71 (not 27.7 ± 0.7)	Ar/Ar	Ferrusquía-Villafranca et al. (2016, p. 201, table B.4, fig. C1)	FV14-174	27.829 ± 0.716	Biotite
Yucudaac Andesite	28.2 ± 0.6	K–Ar	Ferrusquía-Villafranca et al. (1974, p. 257, table 2)	FV69-182 (whole rock)	28.939 ± 0.6	Whole rock

(continued on next page)

Appendix B (*continued*)

Lithostratigraphic Unit	Original Age (Ma)	Dating Analysis	Reference	Sample	Recalculated Age (Ma) (this study)	Mineral
"	29.6 ± 0.6	K–Ar	Ferrusquía-Villafranca et al. (1974, p. 258, table 2)	FV69-182	30.376 ± 0.6	Biotite
"	28.9	Mean age[a]	Ferrusquía-Villafranca et al. (1974, p. 258).	–	Not applicable	–
Chilapa Formation	30.6 ± 0.77	U–Pb	Jiménez-Hidalgo et al. (2018b; 2019, pp. 188–189)	YOL17-10	Not applicable	Detrital zircon
"	30.62 ± 0.67	U–Pb	This study	YOL19-10	Not applicable	Detrital zircon
"	40.3 ± 1.0 Ma	Ar/Ar	Ferrusquía-Villafranca et al. (2016, p. 200, table B.4)	FV14-204	40.561 ± 1.009	K feldespar (glass shards)
Nundichi "Group"	32.9 ± 0.9	K–Ar	Martiny et al. (2000, p. 81, table 1)	CON-101	Unnecessary	Biotite
Yucudaac Andesite	35.7 ± 1.0	K–Ar	Santamaría-Díaz et al. (2008, p. 500, table 1)	AS-03 (whole rock)	Unnecessary	Whole rock
Llano de Lobos Tuff	25.9 ± 0.5	K–Ar	Ferrusquía-Villafranca et al. (1974, p. 257, table 2)	FV69-180 (biotite)	26.579 ± 0.5	Biotite
"	26.5 ± 1.0	K–Ar	Ferrusquía-Villafranca et al. (1974, p. 257, table 2)	FV69-180	27.194 ± 1.0	Not stated
"	26.2	Mean age[a]	Ferrusquía-Villafranca et al. (1974, p. 257)	–	Not applicable	–
"	30.0 ± 0.8	Ar/Ar	Cerca et al. (2007, p. 16, table 2)	TAM-1 (all)	Uncorrected[b]	Biotite
"	31.6 ± 1.0	Ar/Ar	Cerca et al. (2007, p. 16, table 2, Fig. 9)	TAM-5 (all)	Uncorrected[b]	Plagioclase/glass shards
Laccolith intruding Yanhuitlán Formation	40.5 ± 1.7	K–Ar	Martiny et al. (2000, p. 78, table 1)	CON-7	Unnecessary	Hornblende
"	43.0 ± 1.2	Ar/Ar	Cerca et al. (2007, pp. 15–16, table 2, Fig. 9)	YAN-7 all	Uncorrected[b]	Plagioclase
"	49.0 ± 8.0	Pb-alpha	Schlaepfer et al. (1974, p. 243)	LG-123	Not applicable	Zircon

[a] Mean of previous two dates.
[b] Fluence monitor data not published previously or otherwise available.

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