Lower Cretaceous (Aptian-Albian) Bisbee Group, Arizpe area, northern Sonora, Mexico: Integrated biostratigraphy, age and provenance from U-Pb and Hf isotopes

Carlos M. González-León[1,*], María Isabel Sierra-Rojas[1,a], Robert W. Scott[2], Luigi A. Solari[3], Timothy F. Lawton[4], Mélanie Noury[1], and Michelle Vázquez-Salazar[5]

[1] *Estación Regional del Noroeste, Instituto de Geología, Universidad Nacional Autónoma de México, Hermosillo, Sonora, 83000, Mexico.*
[2] *Precision Stratigraphy Associates, 149 W. Ridge Road, Cleveland Oklahoma 74020, USA.*
[3] *Centro de Geociencias, Universidad Nacional Autónoma de México, Campus Juriquilla, Santiago de Querétaro, QRO, 76001, Mexico.*
[4] *Bureau of Economic Geology, Jackson School of Geosciences, The University of Texas at Austin, Austin, Texas 78758, USA.*
[5] *Universidad de Sonora, Departamento de Geología, Hermosillo, 83000, Mexico.*
[a] *Present Address: Departamento de Geociencias, Universidad de Los Andes, Bogotá, 111711, Colombia.*
** cmgleon@unam.mx*

ABSTRACT

New data on the stratigraphy, biostratigraphy, detrital zircon U-Pb, and Hf isotope geochronology of a Lower Cretaceous succession of the Bisbee Group in northern Sonora, Mexico that accumulated in the Altar-Cucurpe sub-basin help to constrain ages of their formations and documents the detrital provenance. These tectonically shortened strata, studied in the Arizpe area, crop out in the Cerro La Ceja block (CCB) composed of the upper Morita Formation, the complete Mural Limestone, and Cintura Formations, and the lower part of La Juana Formation. The Sierra Los Azulitos block (SAB), composed of the Mural Limestone, is thrust eastward over the CCB. A measured section of the Mural Limestone in the SAB block includes the upper Tuape Shale, Los Coyotes, Cerro La Puerta, and part of the Cerro La Espina members whose age is constrained as upper Aptian to lower Albian based on benthic and planktonic foraminifera, bivalves and echinoderms. The age of the boundary between the Morita and Tuape Shale Member is constrained by detrital zircon maximum depositional ages (MDA) of 115.8 ± 1.1 Ma and 113.9 ± 0.8 Ma, respectively. The MDA of the upper Mural is 111.6 ± 1.6 Ma and the MDA of basal Cintura Formation is 108.8 ± 1.1 Ma. The La Juana Formation has upper Albian bivalves and echinoderms.

About one-quarter of the detrital zircon grains dated from the five sandstone samples have Proterozoic ages with age peaks that clearly indicate provenance from basement rocks of southwestern Laurentia. More than two-thirds of the grains are of Jurassic and Early Cretaceous age in about the same proportions, and have main peaks at 166, 150, and 118 Ma. The Jurassic grains may have sources in rocks of the Jurassic Cordilleran continental magmatic arc of southwestern North America, and the most probable sources for the Cretaceous grains are arcs of the Peninsular Ranges batholith that by that time were located adjacent to coastal Sonora. Jurassic and the Early Cretaceous zircons dated from 195.3 to 106.8 Ma both have mixed εHf(t) values that range from 9.53 to -21.28, and T_{DM} model ages between 0.4 to 0.8 Ga for the primitive grains, and 0.8 to 1.3 Ga for the more evolved zircons. The probable source for the Jurassic grains with negative εHf values might be local granites of that age in northern Sonora that have Neoproterozoic T_{DM} model ages. In contrast, sources for the Jurassic zircon with positive Hf values may be Jurassic igneous and metaigneous rocks of the Peninsular Ranges Batholith of the Californias, although data reported are scarce. Similarly, the Early Cretaceous detrital zircon grains with mixed positive and negative εHf values may have provenance from igneous rocks of the Peninsular Ranges Batholith-Sierra Nevada magmatic arc.

Keywords: Bisbee Group; Aptian-Albian biostratigraphy; MDA formational boundaries; U-Pb detrital zircon; Hf isotope; detrital provenance.

RESUMEN

Nuevos datos estratigráficos, bioestratigráficos, de geocronología U-Pb e isótopos de Hf en circones detríticos de una sucesión del Grupo Bisbee que fue acumulada durante el Cretácico Temprano en la sub-cuenca Altar-Cucurpe, en el norte de Sonora, ayudan a precisar las edades de los límites entre sus formaciones y a documentar la proveniencia detrítica. Estas rocas, que fueron estudiadas en el área de Arizpe, presentan un marcado acortamiento tectónico y afloran formando el bloque del Cerro La Ceja (CCB) que está compuesto por la parte superior de la Formación Morita, las secuencias completas de las formaciones Caliza Mural y Cintura, y la parte inferior de la Formación La Juana. El bloque del Cerro La Ceja está cabalgado hacia el oriente por el bloque de la Sierra Los Azulitos (SAB) compuesto por la Caliza Mural. En el bloque SAB se midió una columna de la Caliza Mural que incluye la parte superior del Miembro

González-León, C.M., Sierra-Rojas, M.I., Scott, R.W., Solari, L.A., Lawton, T.F., Noury, M., Vázquez-Salazar, M., 2023, Lower Cretaceous (Aptian-Albian) Bisbee Group, Arizpe area, northern Sonora, Mexico: Integrated biostratigraphy, age and provenance from U-Pb and Hf isotopes: Revista Mexicana de Ciencias Geológicas, v. 40, núm. 3, p. 254-272, DOI: 10.22201/cgeo.20072902e.2023.3.1759.

Lutita Tuape, los miembros Los Coyotes y Cerro La Puerta y la parte inferior del Miembro Cerro La Espina para los cuales se tiene una edad de Aptiano tardío a Albiano temprano, de acuerdo a la identificación de foraminíferos bentónicos y plactónicos, bivalvos y equinodermos. De acuerdo a edades máximas de depósito (MDA) obtenidas por la datación U-Pb de circones detríticos, el límite entre la Formación Morita y la Lutita Tuape está definido por sus edades de 115.8 ± 1.1 Ma y de 113.8 ± 0.9 Ma, respectivamente. La MDA de la parte superior de la Caliza Mural es de 111.6 ± 1.6 Ma, mientras que de la base de la Formación Cintura se obtuvo una de 108.8 ± 1.1 Ma. La edad de la Formación La Juana es Albiano tardío con base a bivalvos y equinodermos.

Cerca de una cuarta parte de los circones detríticos fechados de cinco muestras de arenisca son de edad proterozoica, con picos de edad que claramente indican que sus áreas fuentes fueron rocas del basamento del suroeste de Laurencia. Por otra parte, más de dos terceras parte de estos circones son del Jurásico y del Cretácico Temprano, en proporciones casi iguales, y tienen picos de edad de 166, 150 y 118 Ma. Los granos de edad Jurásica pueden provenir de las rocas del Arco Cordillerano continental del suroeste de Norteamérica y las fuentes más probables para los granos del Cretácico Temprano son los arcos del Batolito Peninsular que en ese tiempo se encontraban adyacentes a la costa de Sonora. Algunos de los circones detríticos del Jurásico y del Cretácico, que tienen edades de 195.3 a 106.8 Ma, dieron valores de εHf(t) mixtos que van de 9.53 to -21.28 y edades modelos T_{DM} entre 0.4 a 0.8 Ga para los granos más primitivos, y de 0.8 a 1.3 Ga para los más evolucionados. Las áreas fuentes más probables para los granos del Jurásico con valores negativos de εHf pueden ser granitos de esa edad, del norte de Sonora, que también tienen edades modelo del Neoproterozoico, mientras que las áreas fuente para los circones del Jurásico con valores positivos de εHf pueden ser rocas ígneas y metaígneas del Batolito Peninsular en California y Baja California, aunque los datos son escasos. Del mismo modo, las áreas fuentes para los circones detríticos del Cretácico Temprano que muestran valores positivos y negativos de εHf puede ser el arco magmático del sistema Batolito Peninsular-Sierra Nevada.

Palabras clave: Grupo Bisbee; bioestratigrafía Aptiano-Albiano; edades máximas de depósito; geocronología U-Pb circones detríticos; isótopos de Hf; procedencia detrítica.

INTRODUCTION

The latest Jurassic-Early Cretaceous Bisbee basin in the border region of southwestern North America records extensional tectonic and sea-level events that were associated with the westward migration of the Jurassic continental magmatic arc and with the opening of the Gulf of Mexico (Dickinson *et al*., 1986; Lawton and McMillan, 1999). The lithologic succession and age of the Bisbee Group that was deposited in this basin document the continental source areas of its clastic sediments and the marginal Gulf of Mexico biostratigraphy that are recorded by several marine incursions. The Early Cretaceous Bisbee basin was located west of the stable Comanche shelf, on the northwestern margin of the Mesozoic Gulf of Mexico (Figure 1). The tectonic and stratigraphic history of this basin relates to the formation of the numerous tectonic blocks and platforms that now compose much of eastern and southern Mexico (Cantú Chapa *et al*, 1985; Martini and Ortega-Gutiérrez, 2018).

Strata of the Bisbee Group were first studied by Ransome (1904), who named its formations in southeastern Arizona. From the base upwards these are the Upper Jurassic Glance Conglomerate, and the Lower Cretaceous Morita Formation, Mural Limestone, and Cintura Formation, whose outcrops extend south into northern Sonora (Taliaferro, 1933; González-León *et al*., 2008). Hayes (1970) named the Bisbee basin as the depocenter where the Bisbee Group accumulated and noted alluvial and fluvial origins for the Glance Conglomerate and the Morita and Cintura formations, and a shallow marine origin for the mixed carbonate and siliciclastic Mural Limestone.

The Bisbee basin in southeastern Arizona, southwestern New Mexico, and northeastern Sonora (Figure 1) is proposed to have formed as a rift associated with extensional tectonics in a back-arc setting and by NW-SE extensional faulting related to the opening of the Gulf of Mexico during the Late Jurassic (Dickinson *et al*., 1986; Lawton and McMillan, 1999; Bassett and Busby, 2005; McKee *et al*., 2005). In this region, the Glance Conglomerate represents early rift alluvial deposits, and the fluvial and shallow marine Lower Cretaceous formations are related to post-rift sedimentation. The Bisbee basin of southern Arizona and northern Sonora has been subdivided by Lawton *et al.* (2020) into the northwest-trending Huachucha and Bootheel,

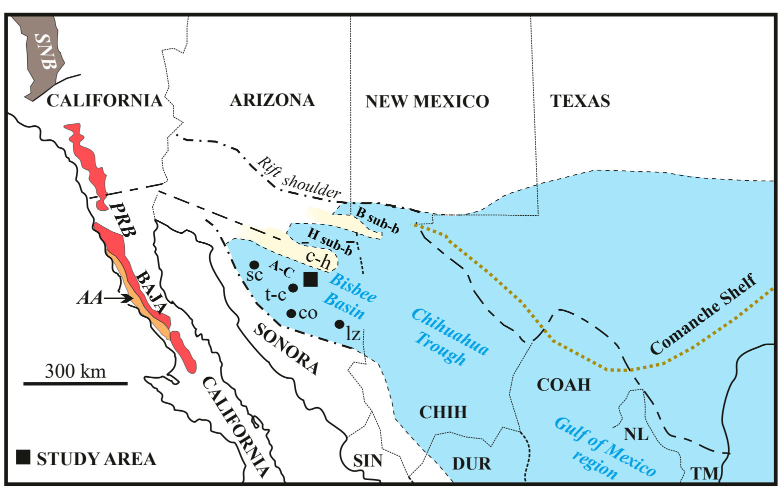

Figure 1. Aptian-Albian schematic paleogeographic setting of the Bisbee Basin within the framework of the Gulf of Mexico region. It shows the location of the study area in Sonora, the basin rift shoulders, the Altar-Cucurpe (A-C), Huachuca (H) and Bootheel (B) sub-basins, the Cananea high (c-h) and other localities mentioned in the text: Cerro de Oro (co), Sierra El Chanate (sc), Tuape-Cucurpe (t-c), Lampazos (lz), Peninsular Ranges batholith (PRB), Sierra Nevada batholith (SNB), and Alisitos arc (AA). Figure modified in part from Lawton *et al.* (2020). States of northern Mexico are Chihuahua (CHIH), Coahuila (COAH), Nuevo León (NL), Tamaulipas (TM), Sinaloa (SIN) and Durango (DUR).

and Altar-Cucurpe sub-basins, located to the north and south of the Cananea paleohigh (McKee and Anderson, 1998), respectively (Figure 1).

Other Lower Cretaceous formations in northern Sonora that are part of the Bisbee Group include the lower Aptian Cerro de Oro Formation (González-León and Lucas, 1995) and its lateral equivalent, the Rancho La Colgada Formation (Monreal *et al.*, 1994; Peryam *et al.*, 2012), that record initial Early Cretaceous marine transgression into the basin (Figure 2). The Rancho La Colgada Formation unconformably overlies marine strata of the Upper Jurassic Cucurpe Formation in the Tuape-Cucurpe region (Figures 1 and 2), and along with the Cerro de Oro Formation, underlies fluvial strata of the Morita Formation. The Mural Limestone overlies the Morita Formation and is composed of the gradational Cerro La Ceja, Tuape Shale, Los Coyotes, Cerro La Puerta Shale, Cerro La Espina, and Mesa Quemada members (Lawton *et al.*, 2004) that represent a carbonate and siliciclastic shallow shelf that was formed during a second marine transgression into the basin. The fluvial strata of the Cintura Formation that overlie to the Mural Limestone are in turn overlain by the carbonate and clastic succession of the La Juana Formation (Mauel *et al.*, 2011) that records a third marine transgression. The La Juana Formation is a lateral equivalent of the upper Albian Nogal Formation (Figure 2) that is the younger part of the *ca.* 2.5 km-thick Lampazos Group, which in southeastern Sonora is a deeper marine facies correlative with the Bisbee Group (Scott and González-León, 1991; Monreal and Longoria, 2000).

In northern Sonora, the Bisbee Group formations have been dated by biostratigraphy and radioisotopic methods (Scott et al., in press). The angular unconformity between the Rancho La Colgada Formation and the underlying Cucurpe Formation records a Late Jurassic-Early Cretaceous tectonic event that is constrained by the *ca.* 150 Ma U-Pb age of a rhyolitic tuff in the upper Cucurpe Formation, and a U-Pb detrital zircon maximum depositional age (MDA) of *ca.* 134 Ma obtained for the Rancho La Colgada Formation (Mauel *et al.*, 2011; Peryam *et al.*, 2012; Lawton *et al.*, 2020). The age of the Morita Formation in northern Sonora is regionally constrained by MDAs of *ca.* 125 Ma at its base (Peryam *et al.*, 2012; González-León *et al*, 2020), and *ca.* 116 Ma at its top (Peryam *et al.*, 2012).

The biostratigraphic Aptian-Albian boundary (113.0 Ma; IUGS, 2020) has been proposed to fall within the lower part of the Mural Limestone close to the contact between the Tuape Shale and the Los Coyotes members (González-León *et al.*, 2008), while the age of the boundary between the Mural Limestone and the Cintura Formation is younger than early Albian by biostratigraphy, but is not constrained by geochronology.

Sandstone compositions of the Morita Formation vary from east to west in the basin in northern Sonora, indicating different provenances. In northeastern Sonora (González-León *et al.*, 2020), sandstone is dominated by quartz-rich arkose to feldspathic litharenite, indicating provenance from a transitional continental block and recycled orogen (Dickinson, 1985), respectively. In north-central Sonora, the Morita sandstones are mostly quartz-rich litharenites that indicate provenance from a recycled orogen (Peryam *et al.*, 2012). In northwestern Sonora, the Morita sandstones are rich in lithic grains, with subordinate quartz grains, and mostly classify as feldspathic litharenite, which indicates provenance from a transitional arc (Jacques-Ayala, 1995).

The lithic grains of the Morita Formation in northeastern Sonora are dominantly felsitic volcanic, but toward the west, in north-central Sonora, the volcanic grains have microlitic and lathwork textures (Peryam *et al.*, 2012). In the Sierra El Chanate, the proportion of felsitic volcanic grains is still dominant, but the volcanic microlitic and vitric grains become more abundant (Jacques-Ayala, 1995). Sandstone composition of a 1146 m-thick section assigned to the Cintura Formation located near the town of Cabullona in northeastern Sonora (Grijalva-Noriega, 1996) grades from a lower quartzose petrofacies into an upper volcanic petrofacies, indicating a shift in provenance from recycled orogen to transitional arc.

Provenance analyses from detrital zircon geochronology are also published for sections of the Morita Formation in northeastern

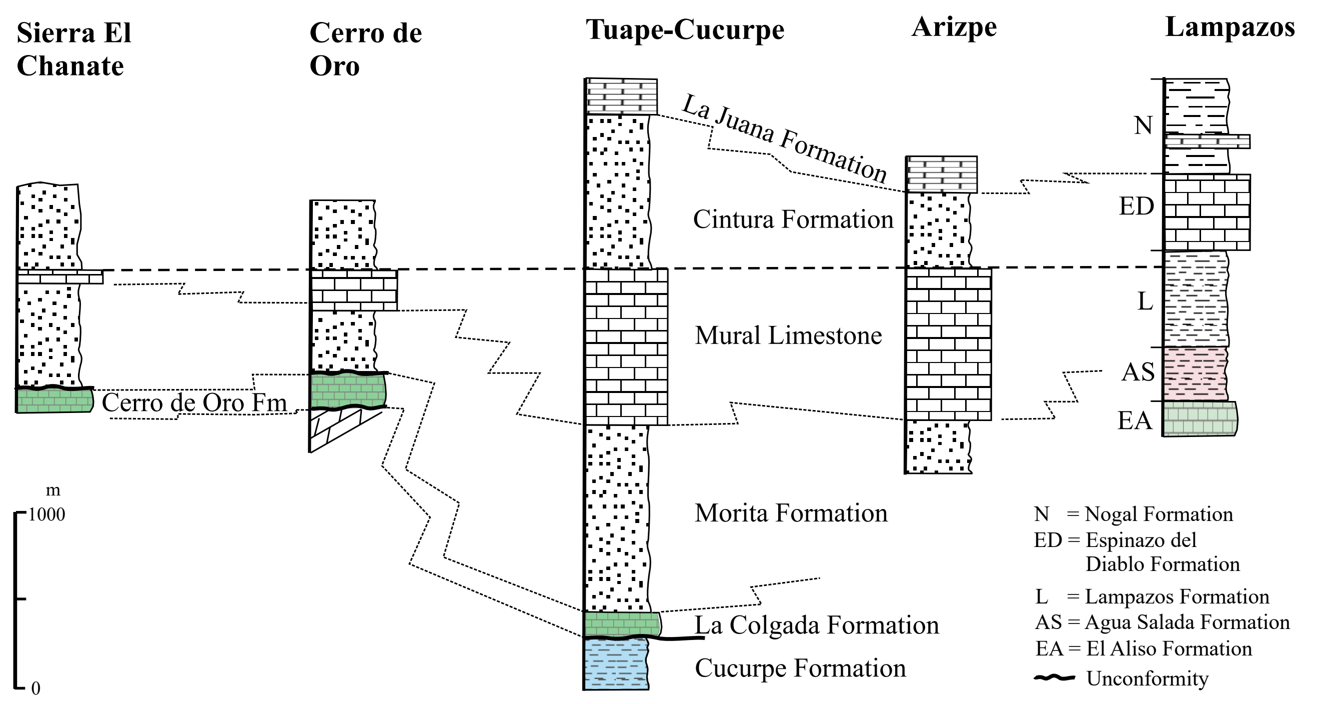

Figure 2. Regional correlation of the formations of the Bisbee Group in selected localities of the northern part of Sonora, and with the formations of the Lampazos Group of the southeastern part of the state.

(González-León *et al*., 2020), and north-central Sonora (Peryam *et al*., 2012), but there are no data published for the Cintura Formation. A Precambrian zircon grain population is well represented in the reported sections of the Morita Formation and has age peaks that indicate provenance from the Proterozoic basement provinces of southwestern Laurentia. Paleozoic grains are subordinate, and less abundant grains are of Permian-Triassic, Jurassic, and Early Cretaceous ages (González-León *et al*., 2020; Peryam *et al*., 2012).

In this work, we report new data on the stratigraphy, biostratigraphy, U-Pb detrital zircon geochronology and coupled Hf isotope analyses of the dated zircon grains of a section of the Bisbee Group that crops out in the Arizpe area, in the central part of the Cucurpe-Altar seaway of north-central Sonora (Figure 1). This locality is essential to studies of the Bisbee basin because it complements previous geologic data and provides new stratigraphic, geochronologic, and biostratigraphic data that constrain the timing of the sedimentary fill. U-Pb geochronology and Hf isotope data from the analyzed detrital zircon grains are used here for the first time to test and confirm previous inferences of detrital provenance and possible source areas.

REGIONAL SETTING AND PREVIOUS WORKS

The older rocks that crop out in the Arizpe area and surroundings consist of strata of the Bisbee Group that are regionally thrust over the Upper Cretaceous Cocóspera Formation, the latter interpreted as a syntectonic conglomerate related to the Late Cretaceous Laramide shortening in northern Sonora (González León, 1978; González León *et al*., 2000; González-León *et al*., 2011). These units are unconformably overlain by an Upper Cretaceous to Paleocene volcanic succession of the Tarahumara Formation that is intruded by contemporaneous granitic plutons, both of which form the Laramide magmatic arc in Sonora. A succession of volcanic and sedimentary rocks of Oligocene and Miocene age that unconformably overlies the older rocks also forms the fill of the extensional basins formed during the Basin and Range tectonic event (González-Gallegos *et al*., 2003; González-León *et al*., 2011).

The stratigraphy of the Bisbee Group in the Arizpe area was reported by González León (1978), while Lawton *et al.* (2004) reported the detailed stratigraphy of the 900 m-thick Mural Limestone that crops out at Cerro La Ceja (Figure 3).

METHODS

Cartography at the scale of 1:50,000 and stratigraphy of the Bisbee Group were refined from González León (1978), and a new stratigraphic column of the Mural Limestone was measured with a Jacob's staff. Limestone samples from the Mural section were thin-sectioned for petrographic classification and microfossil identifications. The biostratigraphy herein reported is based on microfossils described from 28 thin sections and from 7 macrofossil specimens. These studied thin sections, and fossils are housed in the Colección Paleontológica of the Estación Regional del Noroeste, Instituto de Geología, UNAM (ERNO), and bear ERNO-numbers.

Five medium- to coarse-grained sandstone samples, each about 5 kg, were collected for U-Pb geochronology of detrital zircon with the aim to obtain maximum depositional ages of the intervals collected, and to recognize the ages of the detrital populations. These samples were crushed and pulverized in the Laboratorio de Preparación de Muestras, ERNO, and zircon grain separation, mounting and dating were performed at the Laboratorio de Estudios Isotópicos (LEI) of the Centro de Geociencias, UNAM. U-Pb analyses were conducted by laser ablation inductively-coupled plasma mass spectrometry (LA-ICPMS) using a Resonetics M050 (now, Applied Spectra) 193 nm Excimer laser workstation, coupled to a Thermo ICap Qc quadrupole mass spectrometer, according to the methods reported by Solari *et al.* (2018). A 23 µm spot was employed during this whole study for all the U-Pb analyses, alternating unknown zircon crystals with several standards. Standard reference material 91500 was employed as external reference zircon (*ca.* 1062 Ma, Wiedenbeck *et al*., 1995), whereas Plešovice standard zircon acted as a secondary (control) standard (*ca.* 337 Ma, Sláma *et al*., 2008). Raw data were reduced offline using Iolite 3.5 software (Paton *et al*., 2011), including all the error calculations and propagation, and employing the VizualAge data reduction scheme of Petrus and Kamber (2012). The secondary Plešovice standard zircon yielded a mean $^{206}Pb/^{238}U$ age of 338.9 ± 1.4 Ma, in agreement with the accepted age. U–Pb data tables with corrected isotope ratios, ages, and errors are reported in Supplementary Table S1.

Hf isotope geochemistry on detrital zircon has been used by several authors (*e.g.*, Gehrels and Pecha, 2014; Surpless and Gulliver, 2018; Pecha *et al*., 2022) as an additional tool to further support detrital zircon provenance interpretations, provided Hf isotope signatures of the potential source regions are available. With that purpose, we measured the Hf isotope signature on Jurassic and Cretaceous detrital zircon grains dated in each of the five sandstone samples. Hf isotopes were measured by laser ablation multi-collector inductively-coupled plasma mass spectrometry (LA-MC-ICP-MS) on some of the zircon grains previously dated by U-Pb and results are shown in Table S2. Hf analyses were conducted using a spot of 44 µm in diameter, right on top of the 23 µm spot used for the U-Pb analyses, following the methodology employed by Ortega-Obregón *et al.* (2014). The Neptune Plus Jet interface was used to improve sensitivity in laser mode, achieving a tuning optimized to maximize the Hf signal, minimize oxide formation, and avoid the formation of rare-earth element (REE) oxides (cf. Payne *et al*., 2013), as well as control the mass bias. Once properly tuned, the high sensitivity of the Neptune Plus allowed an average total Hf signal of more than 10 V, a value that is like, and, in many cases, exceeds those of other works with a similar setup (*e.g.,* Gerdes and Zeh, 2009; Fisher *et al*., 2011). The tuning was performed in NIST 610 standard glass, employing the same analytical conditions used during analyses. An amount of 9–10 mL/min of N_2 was added to the He carrier gas before the plasma, to increase plasma temperature and decrease oxide formation. The Yb mass bias was calculated using the measured ^{172}Yb and ^{173}Yb masses and the Chu *et al.* (2002) Yb isotope abundances, together with the $^{172}Yb/^{173}Yb$ "true" ratio of 1.35274. The Yb mass bias was also applied on Lu, if Yb and Lu fractionate similarly. The $^{176}Lu/^{175}Lu$ ratio of 0.02656 was also used (Blichert-Toft and Albarède, 1997). To demonstrate the feasibility of this correction, we repeatedly analyzed several natural standard zircon grains, as well as the synthetic zircon grains of Fisher *et al.* (2011) doped with different amounts of REEs. These synthetic zircon grains, which contain a range of REEs much higher than terrestrial zircon crystals, were also used to include the external reproducibility and propagate it onto the internal 2 standard error (2SE, i.e., twice the standard error of the mean; defined as in Paton *et al*., 2011; Fisher *et al*., 2014) measured in unknown zircon grains (*e.g*., Fisher *et al*., 2014). The raw data measured were processed off-line with a data reduction scheme written in Iolite, which corrects the detected interferences, normalizes against the reference zircon (synthetic zircon grains of Fisher *et al*., 2011), and propagates the external reproducibility. The $^{179}Hf/^{177}Hf$ normalizing value of 0.7325 (Patchett and Tatsumoto, 1981) was used. The ^{176}Lu decay constant of 1.876×10^{-11} (Scherer *et al*., 2001) and the chondritic Hf values of Bouvier *et al.* (2008) were used to calculate εHf and depleted mantle

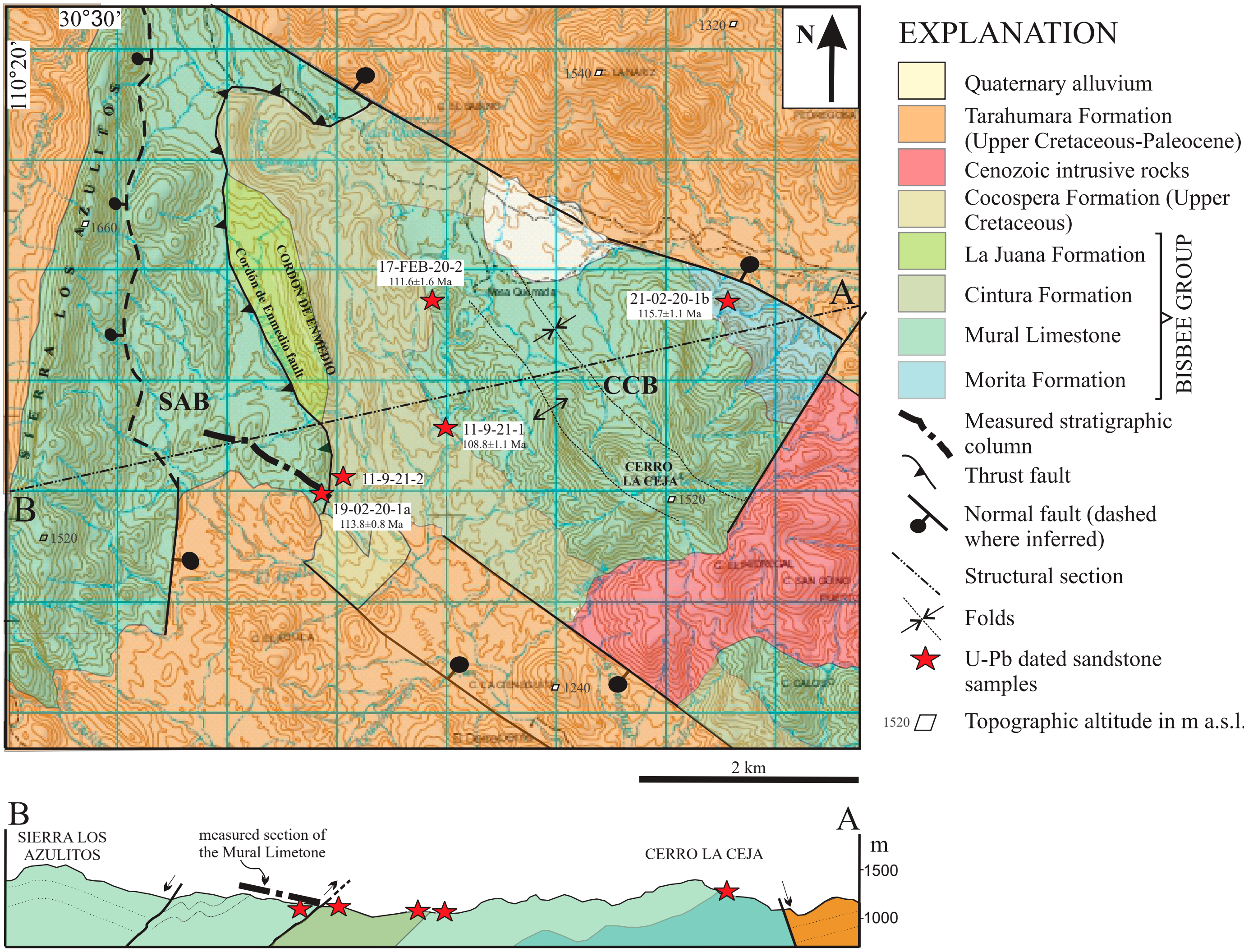

Figure 3. Geologic map of the Arizpe area showing outcrops of the Bisbee Group formations and younger units that include the Cocospera Formation, Tarahumara Formation, and a Tertiary granodioritic pluton. Locations, labels and maximum depositional ages of the dated sandstone samples are indicated. Transect of the measured stratigraphic column of the Mural Limestone (thick dash-dot line) reported in this work, and the structural profile along line A-B are shown. The Cordón de Enmedio thrust fault separates outcrops of the Bisbee Group into Cerro La Ceja (CCB) and Sierra Los Azulitos (SAB) blocks. The base map is taken from the 1:50000 topographic chart Arizpe H12B73 of INEGI (2001; https://www.inegi.org.mx/contenidos/productos/prod_serv/contenidos/espanol/bvinegi/productos/geografia/imagen_cartografica/1_50_000/702825649203.pdf).

(DM) model ages (TDM). The εHf and TDM, calculated employing the chondritic and depleted mantle values, respectively, were generally considered as reflecting minimum ages for the zircon's host magma source. A second model age (TDM_C) was then calculated using a value for the average intermediate crust of $^{176}Lu/^{177}Hf = 0.015$ (Griffin *et al.*, 2002) to ideally project the initial εHf of zircon grains to the depleted mantle model curve and infer possible zircon sources.

RESULTS

Strata of the Bisbee Group in the study quadrangle trend NW-SE and have dips as high as 60°. These rocks are tectonically shortened toward the NE and are herein organized into the eastern Cerro La Ceja block (CCB) and the western Sierra Los Azulitos block (SAB) according to the names of the main physiographic features. These blocks are separated by the east-verging Cordon de Enmedio thrust fault (Figure 3). The CCB is composed of the Morita, Mural, Cintura, and La Juana formations. Because of faults in its eastern and western parts, this block exposes only partial thicknesses of the Morita and La Juana formations, while the Mural and Cintura have complete thicknesses. The SAB is composed of deformed strata of the Mural Limestone that are thrusted eastward over the La Juana and Cintura formations (Figure 3). Oligocene to Miocene normal faults that uplifted the Bisbee Group rocks do not expose the complete stratigraphic column of this region (González-León *et al.*, 2000).

Stratigraphy of the Bisbee Group

The Bisbee Group in the study quadrangle consists of, from the base upwards, the Morita, Mural Limestone, Cintura, and La Juana formations (Figures 3 and 4). Only the uppermost 280 m of the Morita Formation are exposed (Figure 4a) and consist of red to purple shale and siltstone with enclosed beds of coarse- to fine-grained sandstone that have local lenses of pebble conglomerate (González León, 1978). These lithologies are arranged in coarsening-upward cyclic sequences of interpreted fluvial origin.

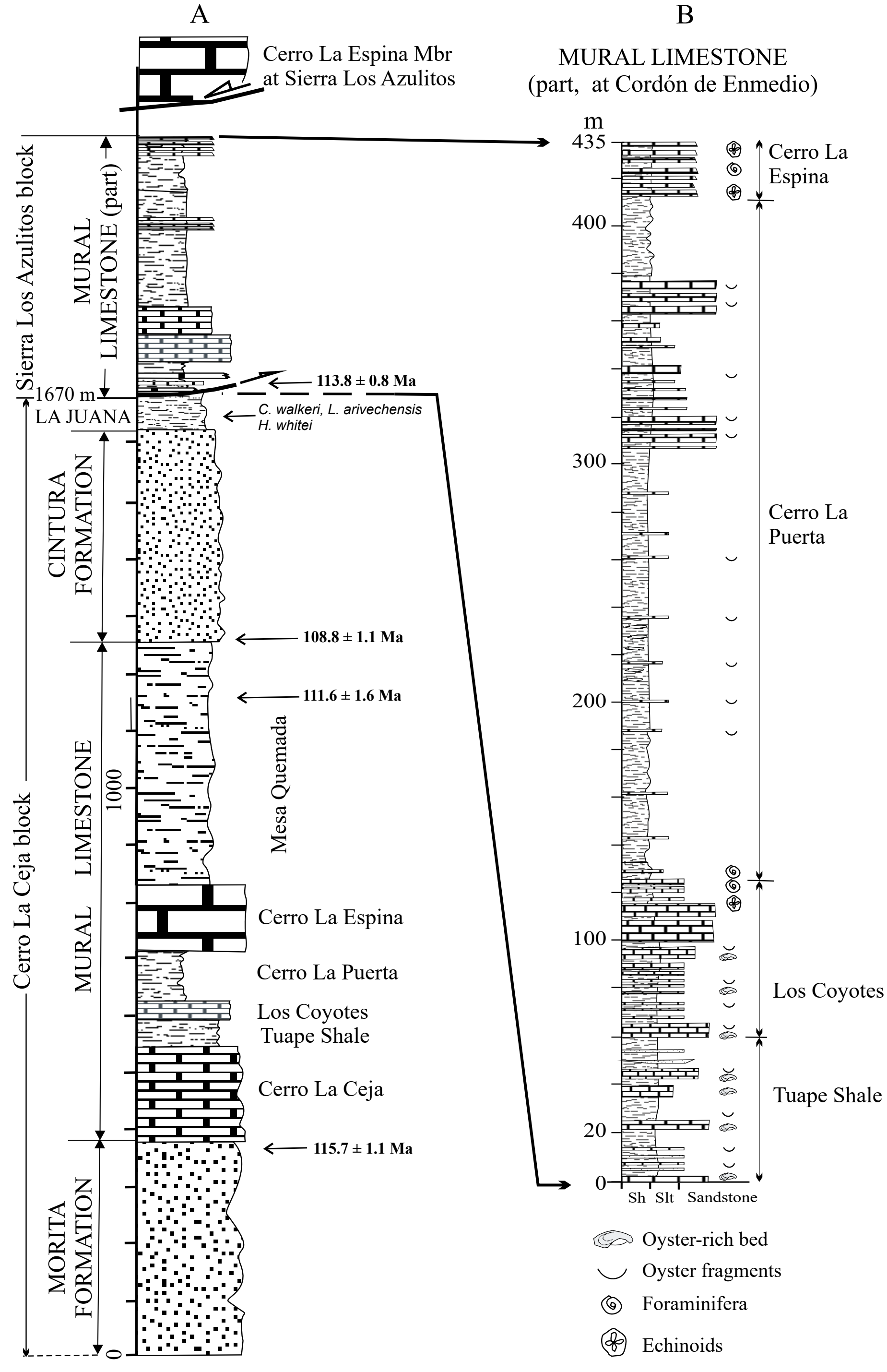

Figure 4. a) Stratigraphic column of the Lower Cretaceous Bisbee Group in the Arizpe area, northern Sonora indicating formations of the Cerro La Ceja block that are overthrust by the Mural Limestone of the Sierra Los Azulitos block. The stratigraphic positions of the maximum depositional ages obtained from the dated sandstone samples are indicated. b) General stratigraphic section of the incomplete Mural Limestone reported in this work from the Cordón de Enmedio locality in the Sierra Los Azulitos block.

In the Cerro La Ceja block the Mural is 900 m thick (Lawton *et al.*, 2004) (Figure 4a) and sharply overlies the Morita Formation on a ravinement surface. Its basal Cerro La Ceja Member is composed of interbedded shale, siltstone, and bioclastic limestone beds that are rich in oysters, and other bivalve shells and fragments; sandstone beds are subordinate. The overlying Tuape Shale is mostly composed of light gray shale with subordinate limestone that grades upwards to interbedded shale and subordinate oyster limestone beds of the Los Coyotes Member. The Cerro La Puerta Shale consists of limestone beds with benthic foraminifera and interbedded shale, and the Cerro La Espina Member is composed of massive bioclastic limestone with coral and rudist mounds. The uppermost Mesa Quemada Member consists of interbedded massive green mudstone, light gray to red siltstone, thin beds of fine-grained sandstone, and bioclastic and oyster-rich shaly limestone beds.

In this work, we describe a previously unreported section of the Mural Limestone that crops out in the Sierra Los Azulitos block (Figure 4b). Although this section is thrust over the Cintura Formation, we measured a continuous thickness of 435 m at the locality of Cordón de Enmedio (Figures 3, 4). Based on its lithostratigraphy and fossil content, this section comprises the upper part of the Tuape Shale, the Los Coyotes, Cerro La Puerta, and the lower part of the Cerro La Espina members. The incomplete Tuape Shale is 60 m thick and consists of light gray to light brown bioclastic limestone beds that are interbedded with massive, yellowish brown to green shale beds up to 15 m thick and a few medium-bedded sandstone beds. The limestone beds are up to 2 m thick and are composed of bivalve shell fragments, including oysters and *Neithea* sp., and serpulid tubes. Articulated, complete oysters are locally present in the bioclastic limestone and in the shale.

The overlying Los Coyotes Member is 67 m thick and consists of yellowish brown to green, massive shale with interbeds of medium-bedded, fine- to medium-grained sandstone, shaly limestone beds up to 40 cm thick with broken and articulated oysters, and grainstone to calcarenite beds mostly composed of shell bioclasts. The uppermost 18 m of this member is composed of light gray to bluish biomicritic limestone in beds up to 50 cm thick that are interbedded with partly covered beds of calcareous shale. The limestone beds are mudstone to wackestone with fragments of bivalves, echinoderms, and abundant foraminifera, including the large foraminifera *Mesorbitolina.*

The overlying Cerro La Puerta Member is 285 m thick and is mostly composed of massive to laminated, light to dark gray calcareous shale with subordinate interbeds of calcareous siltstone, bioclastic and commonly bioturbated shaly limestone and dark gray biomicritic limestone with bivalve and echinoderms fragments. About 180 to 190 m above the base of this member is an interval of medium-bedded shaly wackestone to packstone with bivalve fragments and complete shells of echinoderms. The uppermost 23 m of the measured section is correlated with the Cerro La Espina Member and consists of biomicritic limestone with subordinate calcareous shale that has abundant and complete, moderately preserved echinoderm shells.

In the Cerro La Ceja block, the Cintura Formation gradationally overlies the Mural Limestone and is 372 m thick. It is composed of reddish to purple, massive to locally laminated shale and siltstone with pedogenic calcareous nodules and lenticular sandstone bodies up to 4.5 m thick, rare pebble- to cobble-conglomerate beds up to 1.3 m thick, and ash-fall tuff beds up to 2 m thick. Sandstones of the Cintura Formation in the study area are compositional lithic arkose with up to 30 % quartz, and 9–45 % lithic grains dominated by felsitic volcanics.

The La Juana Formation has an estimated thickness of 100 m, and its lower part is composed of marine bioclastic limestone beds with shell fragments that sharply overlie fluvial red siltstone and sandstone of the Cintura Formation, suggesting a disconformable contact between these units. The bioclastic limestone is interbedded with light gray shale that grades upwards to yellowish and moderately dark gray, massive calcareous shale with thin interbeds of bioclastic limestone that dominates the upper middle part of this unit. Complete to partial shells of oysters, small bivalves, and echinoderms occur in shale intervals.

Biostratigraphy

The Mural Limestone and La Juana Formation are the only marine, fossiliferous units of the Bisbee Group in the Arizpe area. Previously, rudists and oyster bivalves, corals, echinoderms, and benthic foraminifera were reported from limestone beds of the Mural Limestone in the Cerro La Ceja and Sierra Los Azulitos localities of this area (Figure 3) (González León, 1978; Löser, 2011). From the Cerro La Puerta and Cerro La Espina members in the Cerro La Ceja block, an upper Aptian – lower Albian foraminiferal assemblage comprises *Paracoskinolina sunnilandensis* (Maync, 1955), *Praechrysalidina* sp., *Nautiloculina bronnimanni* Arnaud-Vanneau and Peybernès (1978), *Cuneolina* sp. cf. *C. parva* Henson (1948), *Voloshinoides* sp. aff. *V. murgensis* Luperto Sinni and Masse (1993), *Mesorbitolina* cf. *texana* (Roemer, 1849), and *Charentia* sp. cf. *C. cuvillieri* Neumann (1965) (Lawton *et al*., 2004).

The Mural Limestone at Cordón de Enmedio and in Sierra Los Azulitos yield upper Aptian –lower Albian bivalves, echinoderms, and foraminifera (Figures 5 and 6). The bivalves *Crassostrea riograndensis* (Stanton, 1947) (ERNO-8935), and *Quadratotrigonia taffi* (Cragin, 1893) (ERNO-8934) were collected from the lowermost limestone-shale of the Tuape Shale Member. The echinoderm *Pliotoxaster comanchei* (Clark in Clark and Twitchell, 1915) (ERNO 8936 - 8940) was identified in the biomicritic limestone beds in the upper part of the Cerro La Puerta Member and in the overlying Cerro La Espina Member.

Upper Aptian – lower Albian benthic foraminifera from limestone beds in the Los Coyotes Member include *Nezzazata isabellae* Arnaud-Vanneau and Sliter (1995) (ERNO-8907, -8921) (Figure 6, 2-3), *Praechrysalidina* sp. (ERNO-8923) (Figure 6, 6-7), *Voloshinoides sonoraensis* Schlagintweit and Scott, 2015 (ERNO-8908) (Figure 6, 8-10), *Cuneolina parva* Henson (ERNO-8907, -8910) (Figure 6, 11-12), *Novelesia producta*? (Magniez, 1972) (ERNO-8910), *Pseudonummoloculina heimi* (Bonet, 1956) (ERNO-8910), *Paracoskinolina sunnilandensis* (ERNO-8924) (Figure 6, 14-16, *Mesorbitolina* cf. *texana* (ERNO-8912, -8921, -8922; -8923, -8925), and *Bacinella irregularis* Radoičić (1959) (ERNO-8912, -8913). *Nezzazata isabellae* (ERNO-8914) was also identified from a bioclastic shaly limestone bed at 190 m from the base of the section.

Shaly wackestone to packstone beds in the 310 to 319 m interval of the Cerro La Puerta Shale yielded "*Hedbergella*" *planispira* Tappan (1940), ?*Arenobulimina*, and *Microhedbergella pseudodelrioensis* Huber and Leckie (2011) (ERNO-8916, -8928) (Figure 6, 13). The Cerro La Espina Member limestone beds contained *Colomiella tunisiana* Colom and Sigal (in Bolze *et al*., 1959) (Figure 6, 1), ?*Arenobulimina*, *Nezzazata* sp. (ERNO-8917), and *Hedbergella* sp. (ERNO-8929, -8930).

In the Sierra Los Azulitos block thick limestone beds of the Cerro La Espina Member contained *Paracoskinolina sunnilandensis* (ERNO-8918, -8919, - 8920, -8931, -8932, -8933), *Pseudonummoloculina heimi* (ERNO-8918, -8919, -8931, -8933), *Praechrysalidina* sp. and *Nezzazata isabellae* (ERNO-8918), *B. irregularis* (ERNO-8919, -8920, -8933), *C. parva* (ERNO-8919, -8931, -8932), *Mesorbitolina* cf. *texana* (ERNO-8931), the alga *Solenopora* sp. (ERNO-8931), and fragmented rudist toucasids (ERNO-8931) and the rudist bivalve *Coalcomana* sp. (ERNO-8933) (Figure 6, 17).

From green to yellowish shale and bioclastic limestone beds of La Juana Formation we collected complete echinoids of *Hemiaster whitei* Clark, and the bivalves *Ludbrookia arivechensis* (Heilprin, 1891) and *Ceratostreon walkeri* (White, 1880) that together indicate an upper Albian age. For taxonomic and systematic descriptions of the fossils see the Appendix A.

Detrital zircon geochronology

Five sandstone samples from the Bisbee Group were collected in the study area to analyze for detrital zircon geochronology (Figure 3). One sample was analyzed from the Morita Formation, two samples were analyzed from the Mural Limestone, and two other samples were from the Cintura Formation. To visualize detrital age distributions, Kernel density estimator plots of the U–Pb detrital-zircon geochronologic analyses at two-sigma level were constructed using DensityPlotter 8.4 (Vermeesch, 2012), and weighted-mean diagrams of the youngest zircon grains to estimate the maximum depositional age (MDA) were constructed with IsoplotR (Vermeesch, 2018) (Figure 7).

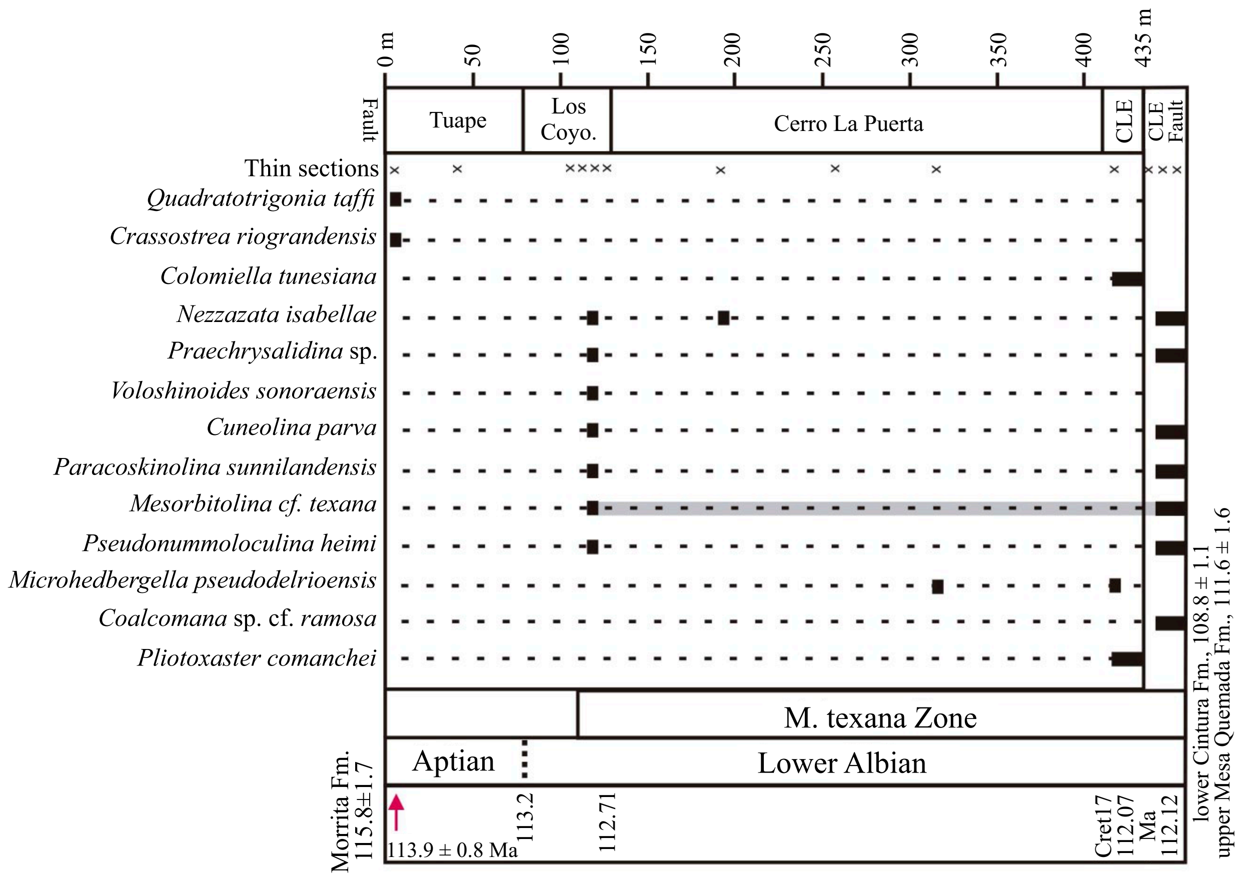

Figure 5. Stratigraphic range chart of important fossil occurrence in the Mural Limestone section reported in this work. CLE: Cerro La Espina.

A medium-grained sandstone bed from the uppermost part of the Morita Formation on the east flank of Cerro La Ceja (Figure 3) is part of a 15 m-thick interval of purple, bioturbated shale that underlies bioclastic limestone beds at the base of the Mural Limestone (sample 21-02-20-1b; coordinate location 30.4761531, -110.2636482; WGS84). The 87 zircon grains from the sample yielded mainly Early Cretaceous (n = 38) and Jurassic (n = 38) ages, and subordinate grains were Triassic (n = 3), Permian (n = 1), and Proterozoic (n = 7). The Early Cretaceous grains have a main peak age of 120 Ma (Figure 7a), and the Jurassic grains have a main peak of 151 Ma with a minor peak of 168 Ma. The seven youngest zircon grains that overlap in age yield a weighted mean age of 115.8 ± 1.1 Ma (MSWD = 0.74), which is interpreted as the MDA for the uppermost part of the Morita Formation at this locality (Figures 4 and 7b).

At Cordón de Enmedio, in the eastern part of the Sierra Los Azulitos thrust block (Figures 3 and 4), a sample of medium- to fine-grained sandstone from the lower part of the Tuape Shale Member is interbedded with shale, calcareous shale, and oyster-bioclastic limestone (sample 19-02-20-1a; 30.4589, -110.3020598). The sample yielded 101 concordant zircon grain ages that contain an important Early Cretaceous age group (n = 44) ranging from *ca.* 111 to 143 Ma. The Jurassic zircon grains compose 35 % of the total dated grains, while Triassic (n = 2) and Paleozoic (n = 2) grains are subordinate. A small Proterozoic population has dispersed ages ranging from 586 to 2500 Ma, and one Neoarchean grain of 2.65 Ga. In the KDE relative probability plot, the Early Cretaceous grains have a mode of 116 Ma, and the Jurassic population has age peaks at 150 and 168 Ma (Figure 7c). The weighted-mean age of the 13 youngest zircon grains from this sample that overlap in age is 113.9 ± 0.8 Ma (MSWD = 0.89) (Figures 4 and 7d).

In the Mesa Quemada Member about ~100 m below the contact with the Cintura Formation, a medium-grained sandstone is interbedded with limestone and shale (sample 17-Feb-20-2; 30.475041, -110.2939629). This sample yielded 86 concordant zircon grain ages, most of which are Proterozoic in age (n = 35; 40 % of the total grains). The Jurassic grains (n = 29) make up 34 % of the total grains, and the Early Cretaceous grains (n = 10) make up 12 %, while Triassic and Permian grains account for the remaining 14 %. The Proterozoic grains show an age peak at 1.66 Ga and subordinate peaks at 1.76, 1.46 and 1.34 Ga; the Jurassic grains have a peak at 154 Ma, the Triassic-Permian group has a peak at 245 Ma, while those of Cretaceous age have a minor peak at 112 Ma (Figure 7e). The weighted mean age of the youngest cluster of three grains that overlap at 2σ error from this sample yield an MDA of 111.6 ± 1.6 Ma (MSWD = 1.3) (Figures 4, 7f).

In the basal 3 m of the Cintura Formation overlying the Mesa Quemada Member is a 1- meter-thick, fine- to medium-grained sandstone (sample 11-9-21-1; 30.466236, -110.291670), which is interbedded with purple, massive shale. Ninety-four dated zircon grains from this sample yielded important age groups of Early Cretaceous (n = 32) and Proterozoic (n = 33) ages. Other subordinate populations are Jurassic (n = 18), Triassic (n = 3), Paleozoic (n = 5), and Neoarchean (n = 3) zircon grains. The Early Cretaceous population has an important age peak at 111 Ma, the Jurassic population has an age peak of 165 Ma, and the Proterozoic grains have minor age peaks at 1.74, 1.65, 1.34, and 1.05 Ga (Figure 7g). The youngest ten grains dated from this sample yield a weighted mean age of 108.8 ± 1.1 Ma (MSWD = 1) (Figures 4, 7h),

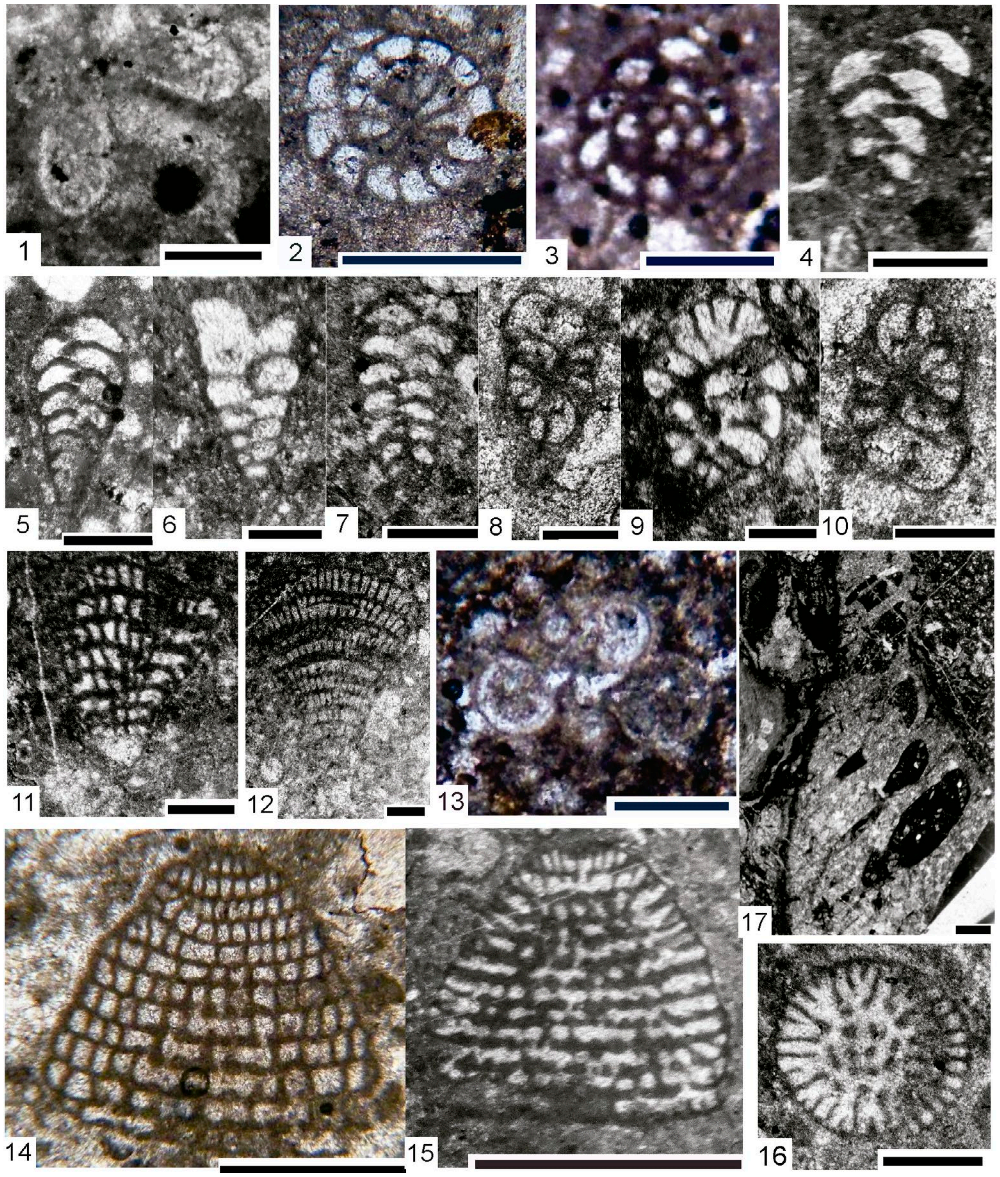

Figure 6. Thin section microphotographs of a colomiellid, important foraminifera and a rudist in the Mural Limestone section of Cordón de Enmedio in the Arizpe area, north-central Sonora. 1, *Colomiella tunesiana* Colom and Sigal; sample 19-20-9B, bar scale 90 microns. 2, 3, *Nezzazata isabellae* Arnaud-Vanneau and Sliter; 2, sample 18-20-3; 3, sample 18-20-2-2. Bar scale is 200 microns except where noted. 4–7, *Praechrysalidina* sp.; 4, sample 20-20-3; 5, sample 18-20-2A; 6, sample 18-20-3D; sample 7, 20-20-3. 8–10, *Voloshinoides sonoraensis* Schlagentweit and Scott; 8, sample 8 18-20-2; 9, sample 9 18-20-3D; 10, sample 10 18-20-3D with bar scale 125 microns. 11, 12, *Cuneolina parva* Henson; 11, sample 20-20-3; 12, sample 18-20-2. 13, *Microhedbergella pseudodelrioensis* Huber and Leckie; sample 2-19-20-8; bar scale 125 microns. 14–16, *Paracoskinolina sunnilandensis* (Maync); sample 2-20-20-3; 14, tangential longitudinal section showing marginal zone; 15, tangential longitudinal section showing central zone; bar scale is 1000 microns; 16, basal section; bar scale 200 microns. 17, *Coalcomana* sp. bioclast with pallial canals, sample 2-20-20-5A, bar scale 1000 microns.

which is considered the MDA for the lowermost part of the Cintura Formation in the Arizpe area.

At Cordón de Enmedio in the upper part of the Cintura Formation, 8 m below the tectonic contact with the Mural Limestone, is a 1-m-thick medium- to coarse-grained sandstone bed (sample 11-9-21-2; 30.459352, -110.301897). From this sample 87 zircon grains contain important age groups of Early Cretaceous (n = 35), Jurassic (n = 28) and Proterozoic (n = 17) ages, and subordinate Triassic (n = 1), Paleozoic (n = 2) and Archean (n = 4) ages. In a KDE plot the Proterozoic ages show a minor peak of 1.16 Ga, the Jurassic grains indicate subordinate age peaks at 152 and 168 Ma, while the Early Cretaceous grains show a major peak at *ca.* 120 Ma (Figure 7i). The nine youngest zircon grains of this sample indicate a weighted mean age of 115.4 ± 1.2 Ma (MSWD = 0.31) (Figure 7j), which is much older than the expected age for the upper Cintura Formation.

Lu-Hf isotopic data

Lu-Hf isotopic data (Supplementary Table S2) were obtained from 15 to 20 detrital zircon grains of Jurassic and Early Cretaceous ages that were measured from each of the five dated sandstone samples. The ablated spots for Hf were the same used for the U-Pb geochronology analyses.

A total of 80 detrital grains from the five samples was measured and is here discussed as a single dataset. U-Pb ages of the analyzed

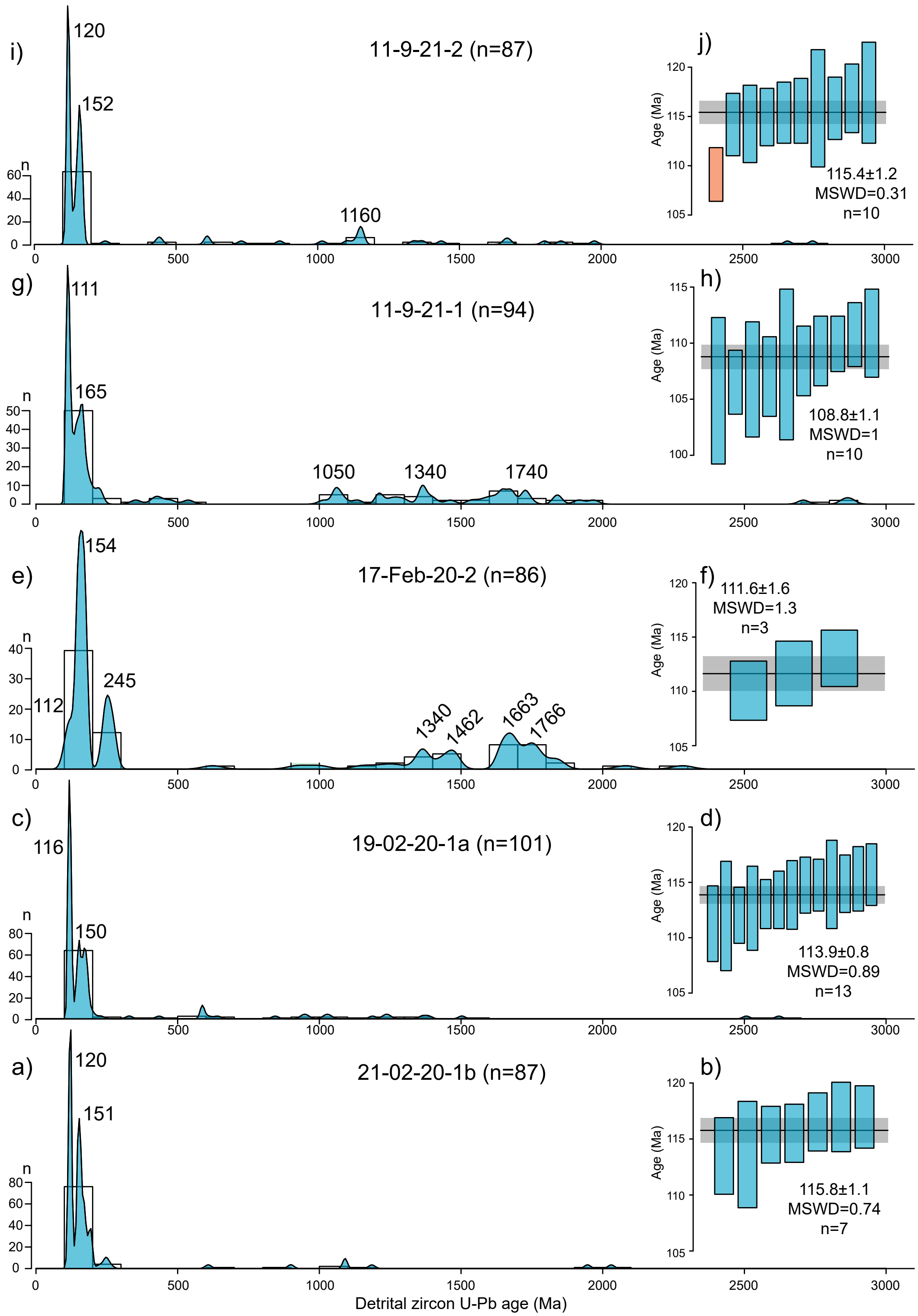

Figure 7. Kernel density estimator plots and weighted mean ages for zircon analyzed by U-Pb geochronology of sandstone sample. a-b) 21-02-20-1b from the upper Morita Formation, c-d) sample 19-02-20-1a from the lower part of the Mural Limestone, e-f) sample 17-Feb-20-2 from upper Mural Limestone, g-h) sample 11-9-21-1 from the lowermost part of the Cintura Formation, and i-j) 11-9-21-2 from the upper Cintura Formation.

zircon grains range from 195.3 to 106.8 Ma, and their initial εHf(t) values range from 9.53 to -21.28. Twelve of the Early Cretaceous zircon with ages from 109.9 to 138.7 Ma have positive εHf(t) from +0.33 to +8.73, indicative of a moderately primitive source, while the other Early Cretaceous grains are more evolved, with εHf(t) values up to -14.42. The analyzed Jurassic zircon grains show a similar trend, with a mixing between primitive (εHf(t) up to +9.53) and negative, more evolved components (εHf(t) between -0.16 and -21.28) (Figure 8). As a consequence, T_{DM} model ages for primitive grains range between 0.4 to 0.8 Ga, whereas the more evolved zircons indicate a contribution of an older crustal component with an age between 0.8 to 1.3 Ga (Figure 8).

DISCUSSION

Chronostratigraphy of the Bisbee Group of the study area

The Bisbee Group succession in the Arizpe area records a part of the Lower Cretaceous sedimentary fill of the central part of the Altar-Cucurpe subbasin of northern Sonora. Its stratigraphy, biostratigraphy, and geochronology data add to the regional knowledge of the evolutionary history of the Bisbee basin (Scott et al., in press). The section in Cerro la Ceja block exposes the upper Morita Formation, Mural Limestone, Cintura Formation, and part of the La Juana Formation. Detrital zircons yield U-Pb maximum depositional ages that approximate depositional ages for the succession. These data are consistent with the biostratigraphic ages for the Mural and La Juana formations.

The MDA of 115.8 ± 1.1 Ma obtained from the upper part of the Morita (Figure 7b) is in close agreement with the 115 ± 1 Ma obtained by Peryam *et al.* (2012) from a reworked ash-fall tuff at the top of this formation in the Tuape-Cucurpe area, located ~50 km southwest of the study area (Figure 1). These data suggest that a regional depositional age of *ca.* 115 Ma is consistent for the boundary between the Morita Formation and Mural Limestone throughout north-central Sonora. Similarly, the age of 113.9 ± 0.8 Ma (Figure 7d) obtained from the lower part of the Mural Limestone in the Cordón de Enmedio section is a little younger than the Morita/Mural age boundary, and also in agreement with its stratigraphic position (Figures 3 and 4). Although the age of 111.6 ± 1.6 Ma (Figure 7f) that was obtained for the sample of the upper Mural Limestone was yielded by few young grains, it is in good agreement with its stratigraphic position located below the base of the Cintura Formation that yielded a younger, more reliable age of 108.8 ± 1.1 Ma.

The ages obtained from the top of the Morita Formation and base of the Cintura Formation constrain the age of the Mural Limestone between *ca.* 116 to 109 Ma, which corresponds well with the regional late Aptian/early Albian biostratigraphic age accepted for this unit in northern Sonora and southeastern Arizona (Scott and Warzeski, 1993; Scott, 2007). The sample collected from the upper Cintura Formation did not yield a near-syndepositional MDA, but its age is interpreted as early Albian considering that it underlies the La Juana Formation that contains late Albian fossils in the study area. Because of its late Albian age, La Juana Formation correlates with the Nogal Formation of the Lampazos Group succession that crops out ~150 km to the southeast

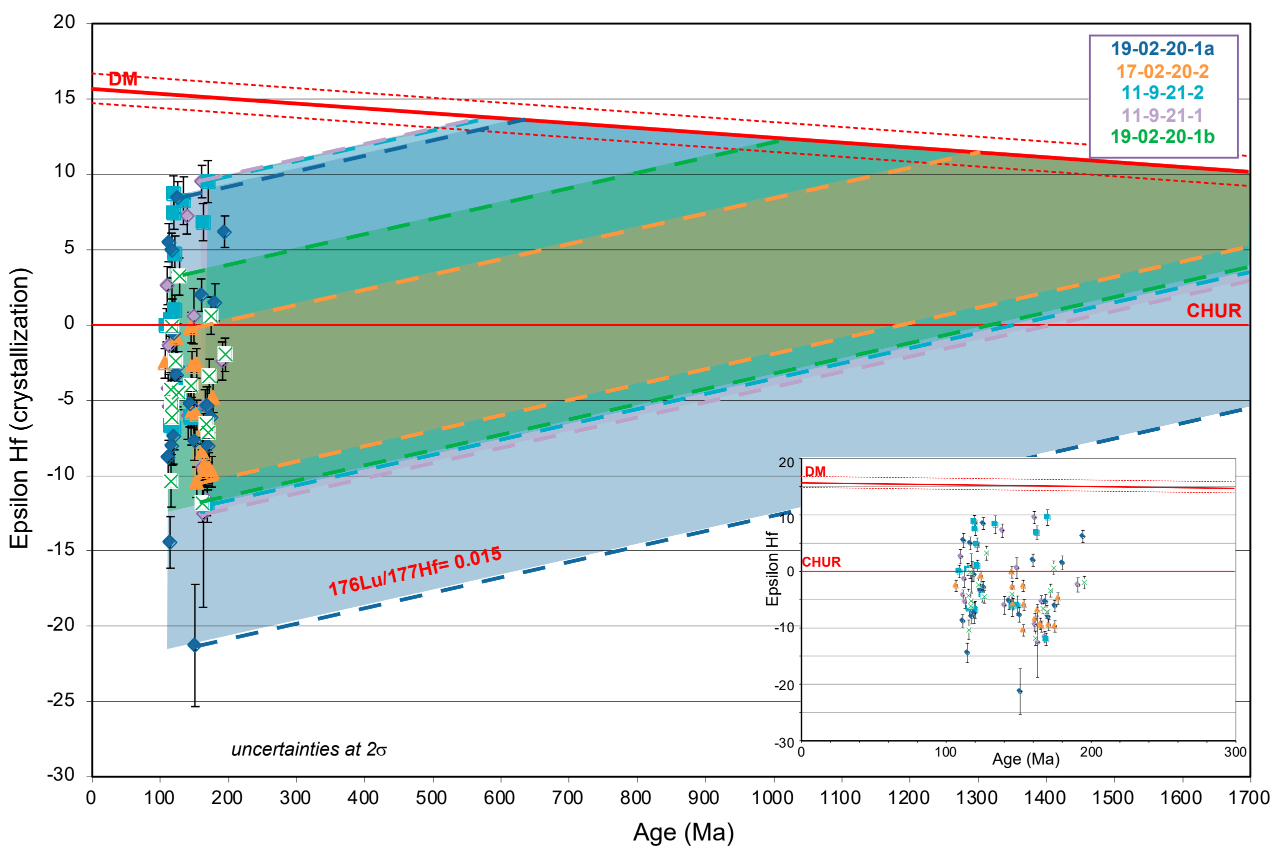

Figure 8. εHf(t) *vs.* time plot of Jurassic and Early Cretaceous detrital zircon the Morita, Mural Limestone and Cintura formations samples of the Bisbee Group in the Arizpe area, northern Sonora, Mexico. The reference parameters are: Depleted mantle (DM), calculated using $(^{176}Hf/^{177}Hf)_0 = 0.28325$ and $(^{176}Lu/^{177}Hf)_0 = 0.0384$ (Blichert-Toft and Albarède, 1997); chondritic uniform reservoir (CHUR), calculated using $(^{176}Hf/^{177}Hf)_0$ = 0.282785 and $(^{176}Lu/^{177}Hf)_0 = 0.0336$ (Bouvier *et al.*, 2008). The crustal evolution path is according to $(^{176}Lu/^{177}Hf)_C = 0.015$ (Griffin *et al.*, 2002).

in east-central Sonora (Figure 1) (González-León, 1988; Scott and González-León, 1991).

The incomplete Mural section of the Cordón de Enmedio locality has a fossiliferous assemblage that indicates the presence of the Aptian-Albian boundary in its lower part, consistent with the U-Pb age of *ca.* 114 Ma (Figure 5d) yielded by sample 19-02-20-1a from the lower part of the Tuape Shale Member.

Biostratigraphy

The age of the Mural Limestone stratigraphic section near Arizpe, Sonora, spans the uppermost Aptian to the lower Albian (Scott *et al.*, in press). The physical stratigraphy and biostratigraphy can be compared with nearby stratigraphic sections at Santa Ana, Santa Marta, and Tuape in northern Sonora (Lawton *et al*., 2004; González-León *et al*., 2008). The age-diagnostic microfossils are *Colomiella tunesiana*, *Voloshinoides sonoraensis*, *Paracoskinolina sunnilandensis*, and *Microhedbergella pseudodelrioensis*. Two bivalve species in the lower limestone-shale of the section also support this age range: the upper Aptian-lower Albian, *Crassostrea riograndensis,* and *Quadratotrigonia taffi* (Scott, 2007). A third species, the lower Albian *Hemiaster comanchei*, is in the uppermost limestone unit. Caprinid wall fragments with diagnostic pallial canals represent the lower Albian *Coalcomana* Coogan (1973).

The pelagic Protozoan tintinnid *C. tunesiana* is widespread in northern Sonora (Gonzalez-León *et al*., 2008) and in the Texas Gulf Coast (Scott, 1990). Its numerical age range is 114.20–108.69 Ma (Scott, 2014). The small benthic foraminifer, *V. sonoraensis,* was discovered and named from the lower Albian Cerro La Espina Member of the Mural Formation in the nearby Cerro la Ceja block (Schlagintweit and Scott, 2015). The large benthic foraminifer *P. sunnilandensis* is widespread in Barremian to lower Albian sections in the Gulf of Mexico and Sonora and its age range is 125.08–109.36 Ma (Scott, 2014). The planktic foraminifer *Microhedbergella pseudodelrioensis* ranges from lower to upper Albian in the North and South Atlantic (Huber and Leckie, 2011). Other benthic foraminifers are long-ranging but span the upper Aptian to lower Albian or younger.

Paleobiogeography

The low diversity of Aptian-Albian planktonic foraminifers in the Mural Limestone in northern Sonoran is remarkable. These sections are located at the northwestern end of the Chihuahua Trough. In comparison, sections farther southeast in the state of Nuevo León in northeastern Mexico document eleven zonal species of open marine planktic foraminifers (Longoria, 1984) and up to 55 species of calcareous nannofossils (Bralower *et al*., 1999). Furthermore, in the Sonoran sections, benthic foraminifers and corals, rudists, and calcareous algae are more diverse than in the Chihuahua Trough and northeastern Mexico. The different biota and paleocommunities represent the shallower, more paralic depositional environments at the northwestern part of the Gulf of Mexico basin. Further, the presence of benthic species with Pacific affinities, such as *Nezzazata isabellae*, suggests a partial connection with Pacific waters.

Detrital zircon provenance

Detrital zircon grains (N = 456) in the five dated sandstone samples are dominated by Early Cretaceous (35 %) and Jurassic (32.5 %) ages composing more than two-thirds of the total grains. Proterozoic grains are 24 % of the total grains, Permo-Triassic grains compose 4.8 %, Paleozoic grains are 3.5 %, and there are only eight grains of Archean age.

The proportion of Early Cretaceous grains varies little from the upper Morita (42.6 %) to the lower Cintura (34 %) and upper Cintura (40.2 %) formations, but are overrepresented in the lower Mural (78.2 %) and underrepresented in the upper Mural Limestone (11.6 %). Similarly, the Jurassic grains vary from 44.8 % in the upper Morita to 33.7 % in the upper Mural, they compose 19.1 % in the lower Cintura and 32 % in the upper Cintura, and are almost absent (2 %) in the lower Mural. The Permo-Triassic grains decrease upwards in the section, from 4.6, 0, 13.9, 3.2, and 1.2 % from the Morita to the Cintura samples. Proterozoic grains compose 8 % of the Morita, 15.8–40.7 % of the lower and upper Mural, and 36–19.5 % of the lower and upper Cintura. The over- and/or under-representation of these populations in the Mural Limestone of the Arizpe area might be explained by an inefficient, or restricted sediment dispersal in a shallow shelf that was located in the middle part of the Altar-Cucurpe subbasin, probably several hundred kilometers from the marginal settings bordering the basin.

The Proterozoic grains have subordinate age peaks of *ca.* 1.7, 1.6, 1.4, 1.3 and 1.1 Ga (Figure 9a). These populations are commonly considered to have direct or recycled provenance from the Mojave, Yavapai and Mazatzal crystalline basement rocks of southwestern North America and from Mesoproterozoic granites that intrude these provinces (Gehrels and Stewart, 1998; Stewart *et al*., 2001). The Paleozoic grains are subordinate in number and have scattered ages; these occur as recycled grains in other detrital successions of Sonora (*e.g.*, González-León *et al*., 2020) and are considered of primary Appalachian sources (*e.g.*, Gehrels *et al*., 2011). The Permo-Triassic grains are also subordinate in number forming a peak of 270 Ma and have possible source in the early Cordilleran continental magmatic arc rocks, whose nearby outcrops are present in northwestern Sonora (Arvizu and Iriondo, 2015).

The Cretaceous and Jurassic ages that compose 67.5 % of the total dated grains, constitute three dominant age groups (Figure 9b). The Jurassic grains have age peaks of *ca.* 150 and 166 Ma that are consistent in each of the analyzed samples (Figure 7e). The Cretaceous population is represented by grains with ages from *ca.* 130 to 107 Ma and a dominant age peak of *ca.* 118 Ma (Figure 9b). This is represented in the analyzed samples by peaks of 111, 116 and 120 Ma, except in the upper Mural, that has a small peak of 112 Ma (Figure 7). The Cretaceous population is nearly coincident with the age group between *ca.* 128 to 112 Ma, and modes near 122 and 116 Ma that Peryam *et al.* (2012) recognized in the upper part of the Morita Formation of the Tuape region. Furthermore, an important gap of Early Cretaceous age is evident between the Jurassic and Cretaceous age groups of our samples, as indicated by a subordinate number of detrital zircon grains with ages from ~145 to 130 Ma (Figure 9b).

The Jurassic age group with a peak of *ca.* 166 Ma is composed of grains with ages from 185 to 158 Ma and most probably indicates provenance from the Jurassic continental magmatic arc of southwestern North America (Busby-Spera, 1988; Lawton *et al*., 2020). Scattered rock outcrops of this arc occur from southern Nevada to southeastern California, southern Arizona and northern Sonora (Haxel *et al*., 2008a), and this peak is within the age range of *ca.* 190 to 158 Ma assigned to the arc in northern Sonora (González-León *et al.*, 2021).

The age group with a peak of *ca.*150 Ma in the studied samples is composed of zircon grains that have ages from 156 to 145 Ma. A similar age peak is also present in detrital samples of the upper part of the Morita Formation in Tuape (Peryam *et al*., 2012). Regional magmatism that might be a source for this age group is indicated by silicic ash-fall tuffs with ages near 150 Ma that are interbedded with marine shales of the Late Jurassic Cucurpe Formation in the Tuape area (Mauel *et al*., 2011). Also, scarce plutonic and volcanic rocks in southern Arizona and northern Sonora have been dated from *ca.* 153 to 141 Ma (Anderson *et al*., 2005; Haxel *et al*., 2005; Haxel *et al*., 2008b).

Age of the Early Cretaceous population is contemporaneous with time of development of the magmatic arcs that formed the Peninsular Ranges batholith of southern California and Baja California (*e.g.*,

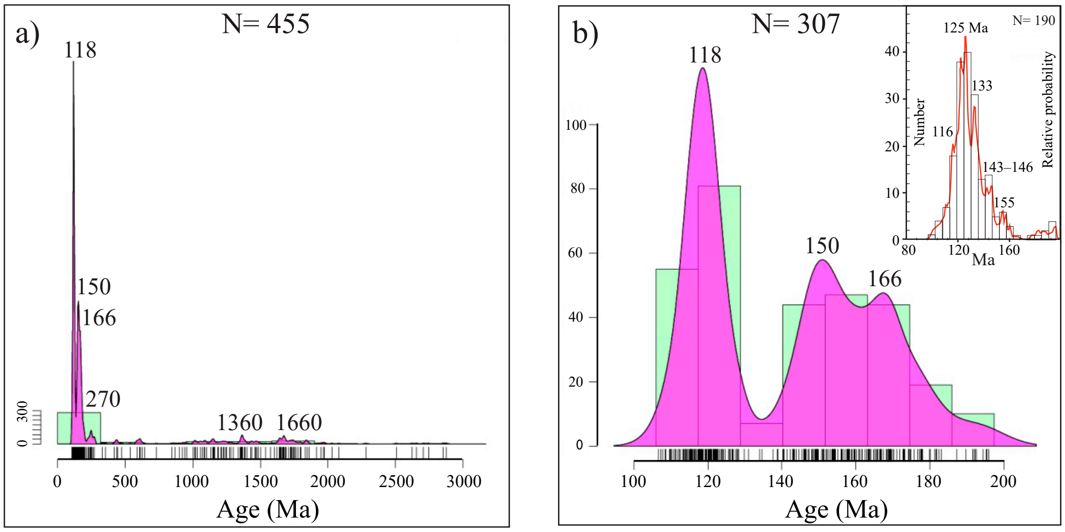

Figure 9. a) Kernel density estimator plot with age distributions for the total number of analyzed zircon from the Morita, Mural, and Cintura formations sandstone of the Bisbee Group in the Arizpe area. b) The KDE plot for the Cretaceous and Jurassic age groups shows the main age distributions. Inset in b): a histogram and relative probability density plot of detrital zircon ages (N = 190) reported by Alsleben *et al.* (2012) from the Cretaceous intra-arc and deformed successions in Baja California showing the main age distributions.

Ortega-Rivera, 2003; Shaw *et al.*, 2003; Premo *et al.*, 2014; Contreras-López *et al.*, 2021; Schwartz *et al.*, 2021), that by that time bordered the Altar-Cucurpe subbasin on the west. The hypothesis that these arcs acted as source of detritus that were mostly transported by rivers to the east, into the Bisbee basin, was largely favored by many authors (*e.g.*, Jacques-Ayala, 1995; Mauel *et al.*, 2011, Peryam *et al.*, 2012; Sharman *et al.*, 2015; Lawton *et al.*, 2020; Schwartz *et al.*, 2021); our detrital zircon geochronology and geochemistry supports this inference.

Detrital zircon reported by Alsleben *et al.* (2012) from the Alisitos intra-arc and Cretaceous deformed successions of Baja California, record nearly continuous magmatism from Late Jurassic through Early Cretaceous, and some of their age peaks (inset in Figure 9b) nearly compare to the 116, 120–122 and 153 Ma peaks in the Bisbee Group samples of Arizpe (Figure 7) and of Tuape (reported by Peryam *et al.*, 2012) in northern Sonora. Similarly, a possible source for the youngest zircon grains in our upper Mural and lower Cintura samples may be the 110 to 89–86 Ma magmatism of the La Posta suite plutons in the PRB (Premo *et al*, 2014; Shaw *et al.*, 2014).

U-Pb ages of magmatic zircon in andesite clasts reported from the lower Morita Formation in Tuape yielded ages from 145 to 133 Ma (Peryam *et al.*, 2012), which coincide with age of the apparent Early Cretaceous magmatic gap recorded by our Bisbee Group detrital zircon samples (Figure 9b). This may indicate that this was not a complete lull in magmatism, as also indicated by the apparently continuous Late Jurassic-Early Cretaceous detrital zircon ages from Baja California (Alsleben *et al.*, 2012).

Hf isotope analyses

The element Hf in detrital zircons may be a clue to sediment provenance; however, its utility in interpreting sediment sources of Jurassic and Cretaceous strata in Sonora is currently limited by a paucity of data. While the εHf values of detrital zircon grains from the Bisbee Group in the Arizpe area spread from primitive to evolved values for both Jurassic and Cretaceous ages, the only available data to compare them with are from Jurassic plutons (González-León *et al.*, 2021; Valencia-Moreno *et al.*, in press) that show negative εHf(t) values. Lower Cretaceous igneous rocks older than 100 Ma are not present in Sonora.

The same behavior occurs for Jurassic plutons in the neighboring Mojave Desert of southeastern California that also yielded negative εHf(t) values and T_{DM} model ages averaging 1700 ± 190 Ma for zircon in two Middle Jurassic rocks, and 1820 ± 160 Ma in three Late Jurassic plutons (Howard *et al.* 2023).

Early Cretaceous plutons from the western zone of the Peninsular Ranges batholith in southern California yielded positive zircon εHf(t) values from 3.1 to 11.4, corresponding to T_{DM} model ages of *ca.* 0.4 to 0.9 Ma (Shaw *et al.* (2014)), while Jurassic metaigneous rocks and Early Cretaceous plutons and xenoliths from this batholith in the northern Baja California Peninsula have positive zircon εHf(t) values (Contreras-López *et al.*, 2021).Similarly, Hf positive values are reported from volcanic and plutonic rocks of the Alisitos arc in this region (Busby *et al.*, 2023) (Figure 1).

Magmatic zircons of the Jurassic Cordilleran Continental magmatic arc in the southern Mojave Desert that have negative εHf(t) and old Paleoproterozoic T_{DM} model ages are not a probable source for the Jurassic zircon of the studied samples, which have Neoproterozoic and Mesoproterozoic model ages. A more probable source for the Hf negative zircon grains in the studied samples might be the Jurassic granites of Sonora that have Neoproterozoic T_{DM} model ages.

Probable sources for our Jurassic detrital zircon with positive Hf values are Jurassic igneous and metaigneous rocks of the PRB of California and Baja California (Shaw *et al.*, 2014; Contreras-López *et al.*, 2021), although data reported are scarce. Similarly, the Early Cretaceous igneous rocks of the PRB that have dominantly positive εHf(t) values represent a plausible source for the same age detrital zircon with positive Hf of Sonora, as both share the same Paleozoic and Neoproterozoic T_{DM} model ages.

Jurassic and Early Cretaceous detrital zircon with mixed negative and positive Hf values, like those in the Arizpe area, are present in middle Cretaceous formations of the Mojave Desert in southern Nevada and are interpreted by Balgord *et al.* (2021) to be sourced in batholithic rocks of the Sierra Nevada (Lackey *et al.*, 2012). The similar detrital zircon composition between both successions also suggests that detritus in the Altar-Cucurpe subbasin strata of Sonora have possible sources from the PRB-Sierra Nevada magmatic arc system.

CONCLUSIONS

A section of Lower Cretaceous Mural Limestone of the Bisbee Group in the Arizpe area of northern Sonora, Mexico provides new data that constrains the ages of the members and provenances of the siliciclastic units. The Mural crops out in the western block of Sierra Los Azulitos, which is thrust over the eastern Cerro La Ceja block. The latter exposes the upper part of the Morita Formation, the entire Mural Limestone, as well as the Cintura and lower part of the La Juana formations.

New biostratigraphic data from the Tuape Shale, Los Coyotes and Cerro La Puerta members and the lower part of Cerro La Espina Member support the upper Aptian to lower Albian age of the Mural Limestone (Lawton *et al*., 2004). This age range is supported by a shallow marine foraminiferal assemblage, sparse pelagic colomiellids and planktonic foraminífera and rare benthic megafossils.

Detrital zircon geochronology of five sandstones from the Morita, Mural and Cintura formations yield weighted-mean MDA values that constrain the ages of these units. The upper part of the Morita Formation is 115.8 ± 1.1 Ma, and the basal Tuape Shale is 113.9 ± 0.8 Ma, which approximates the age of the Morita and Mural boundary. The age of the Mural/Cintura boundary is bracketed by 111.6 ± 1.6 Ma in the uppermost Mesa Quemada Member and by 108.8 ± 1.1 Ma in the basal Cintura Formation. The overlying La Juana Formation contains upper Albian bivalves and echinoderms.

Sandstone petrography, detrital zircon ages, and Hf isotope composition of the Bisbee Group formations in northern Sonora support the origin of sediments from nearby juvenile to evolved magmatic arcs. Detrital zircon grains in the Morita and Cintura formations and the Mural Limestone are mainly Jurassic and Early Cretaceous in age and few are of Proterozoic, Paleozoic or Triassic age. Four age peaks are 166 Ma, 150 Ma, 118 Ma, and 111 Ma. Jurassic ages are related to the Continental Jurassic magmatic arc. The Cretaceous ages are similar to ages of magmatism in the Sierra Nevada-Peninsular Ranges batholiths, which were near the coast of Sonora at that time (Lawton *et al*., 2020). In Sonora, Early Cretaceous magmatism older than about 100 Ma is unknown (Mauel *et al*., 2011; Peryam *et al*., 2012; Lawton *et al*., 2020; González-León *et al*., 2020). Similar zircon ages are also found in the Alisitos intra-arc and Cretaceous deformed strata of Baja California or even in the La Posta magmatism (Alsleben *et al*., 2012).

ACKNOWLEDGMENTS

This work was supported by UNAM-PAPIIT Project No. IN101820. M. I. Sierra Rojas acknowledges to DGAPA-UNAM for the postdoctoral scholarship awarded between 2019 and 2021, facilitating the completion of the project "Tectonic and stratigraphic study of the Lower Cretaceous in Sonora, Arizpe-Cucurpe region" in Estación Regional del Noroeste, Instituto de Geología, UNAM. We appreciate helpful technical support for rock samples preparation provided by Aimé Orcí Romero and Elizard González Becuar at Estación Regional del Noroeste, Instituto de Geología, UNAM. We greatly appreciate to Consejo de Paleontología, INAH for permit granted for fossil collection and handling through Project No. 401.1S.3-2020/162, and to Sr. Ricardo Paz Pellat and Sr. Ignacio "Nacho" Medrano for allowing us to do field work into their ranch properties. The manuscript was greatly improved by important and constructive reviews received from Dr. Francisco Javier Cuen Romero and an anonymous reviewer.

SUPPLEMENTARY MATERIAL

Supplementary Tables S1 "U-Pb data of the analyzed sandstone sample from the Bisbee Group formations in the Arizpe area, northern Sonora, Mexico" and S2 "Hf isotope data" are available online at www.rmcg.unam.mx, in the preview of this paper.

APPENDIX A.
TAXONOMY AND SYSTEMATIC DESCRIPTIONS

Taxonomy and systematic descriptions of important fossils identified either in thin sections or as hand samples from the Mural Limestone in the section of Cordón de Enmedio, Arizpe area, northern Sonora, Mexico.

Systematic Micropaleontology

Higher-level systematic classification of bowl-shaped colomiellid microfossils with a calcite hyaline wall is uncertain.

Family Colomiellidae Bonet, 1956
Genus *Colomiella* Bonet, 1956
Colomiella tunisiana Colom and Sigal, 1959 *in* Bolze *et al*., 1959
Figure 3, 1

Remarks. The suture between the neck and the bowl is slanted and the base of the bowl is smoothly rounded to slightly angular. This species ranges from the latest Aptian to early Albian 114.20 Ma to 108.69 Ma (Scott, 2014). In other Sonoran localities, this species is in the Cerro La Puerta Shale and the Cerro La Espina members of the Mural Formation (Gonzalez-León *et al*., 2008) and in the basal Lampazos Formation (Saucedo-Samaniego *et al*., 2021). In northeastern Sonora and southwestern Arizona, it is in the Canova Member of the Mural Limestone at Sierra del Caloso (Scott and Warzeski, 1993). In the Arizpe section, this species is in the lower part of the Cerro La Espina Member. In the Texas subsurface, it is in the upper Aptian-lower Albian Tamaulipas Formation (Scott, 1990).

Systematic classification by Boudagher-Fadel (2018) and Schlagintweit (2020), in which full references to suprageneric categories are provided.

Phylum Foraminifera Pawlowski *et al*., 2013
Class Globothalamea Pawlowski *et al*., 2013
Subclass Textulariana Mikhalevich, 1980
Order Textulariidae Delage and Hérouard, 1896
Superfamily Nezzazatoidea Hamaoui and Saint- Marc, 1970
Family Nezzazatidae Hamaoui and Saint-Marc, 1970 [LT-p. 86]
Subfamily Nezzaztinae Hamaoui and Saint-Marc, 1970
Nezzazata Omara, 1956
Nezzazata isabellae Arnaud-Vanneau and Sliter, 1995
Figure 3, 2-3

Remarks. Five trochospiral specimens have 10–12 chambers per whorl with a mean diameter of 284 microns, which is slightly larger than the maximum diameter of 200 microns of the upper Aptian-lower Albian Pacific specimens (Arnaud-Vanneau and Sliter, 1995). Similar but larger specimens were described in the upper Albian Mal Paso Formation in southwest Mexico and identified as *Nezzazata* sp. cf. *N. isabellae* (Filkorn and Scott, 2011). In the Arizpe section, this species ranges from the Los Coyotes Member to the Cerro La Espina Member.

Superfamily Textularioidea Ehrenberg, 1838
Family Chrysalidinidae Neagu, 1968
Praechrysalidina Luperto Sinni, 1979
Praechrysalidina sp.
Figure 3, 4-7

Remarks. These conical tests are biserial in cross-section; the arcuate overlapping septa define a terminal aperture and span one-half to two-thirds test diameter; the wall is microgranular calcite; mean test height is 482 microns, mean width is 268 microns, mean h/w ratio is 1.85. These specimens are about half the size of *Praechrysaldina infracretacea* Luperto Sinni (1979) and their septa are not refracted. Similar specimens are in the upper Albian Mal Paso Formation, Guerrero, Mexico (Filkorn and Scott, 2011. In the Arizpe section, this taxon ranges from the Los Coyotes to the Cerro La Espina members.

Superfamily Ataxophragmioidea Schwager, 1877
Family Ataxophragmiidae Schwager, 1877
Voloshinoides Barnard and Banner, 1980
Voloshinoides sonoraensis Schlagentweit and Scott, 2015
Figure 3, 8-10

Remarks. This species was first identified in the lower Albian Cerro La Espina Member of the Mural Formation at the Cerro la Ceja section about 20 km northwest of the Arizpe section. In the Arizpe section this species is in the Los Coyotes Member.

Family Cuneolinidae Saidova, 1981
Cuneolina d'Orbigny, 1839
Cuneolina parva Henson 1948
Figure 3, 11-12

Remarks. Filkorn and Scott (2011) reviewed the taxonomy of Albian-Cenomanian cuneolinids in North America and considered that *C. parva* has priority over *Cuneolina walteri* Cushman and Applin (1947) in Scott and Gonzalez-León (1991). In the Arizpe section *C. parva* ranges from the Los Coyotes to the Cerro La Espina members.

Order Loftusiida Kaminski & Mikhalevich in Kaminski (2004)
Suborder Orbitolinina Kaminski (2004)
Superfamily Orbitolinoidea Martin (1890)
Family Orbitolinidae Martin (1890)
Subfamily Dictyoconinae Moullade (1965)
Paracoskinolina Moullade, 1965
Paracoskinolina sunnilandensis (Maync, 1955)
Figure 3, 14-16

Remarks. The marginal zone in the basal section is subdivided by short, vertical radial partitions alternating with shorter partitions; in the longitudinal section the marginal zone is without transverse partitions; the central zone has vertical pillars that are aligned with pillars in adjacent chambers (Loeblich and Tappan, 1988, p. 162). In the Arizpe section *P. sunnilandensis* ranges from the Los Coyotes to the Cerro La Espina members. Range is Barremian-lower Albian, 125.08–109.36 Ma (Scott, 2014).

Subfamily Orbitolininae Martin, 1890
Mesorbitolina Schroeder, 1962
Mesorbitolina cf. *texana* (Roemer, 1849)

Remarks. Although none of the specimens in thin sections from the Arizpe section show the proloculus, *M. texana* is the most common species in the lower Albian strata in Mexico. In the Arizpe section, it is present in the Los Coyotes Member and in the Cerro La Espina Member. In the Gulf Coast, *M. texana* ranges from 113.70–108.11 Ma (Scott, 2014).

Superfamily Miliolacea Ehrenberg, 1839
Family Hauerinidae Schwager, 1876
Subfamily Haueritinae Schwager, 1876
Genus *Pseudonummoloculina* Calvez, 1986
Pseudonummoloculina heimi (Bonet, 1956), emended Conkin and Conkin, 1958

Remarks. In the Arizpe section, this species is in the Los Coyotes Member and in the Cerro La Espina Member. This species is widespread in Mexico, in the U.S. Gulf Coast, and in the Mediterranean area. It is in the El Abra Limestone on the Valles-San Luis Potosí Platform (Omaña *et al.*, 2019). *P. heimi* ranges from lower Albian to upper Cenomanian, 110.56–92.03 Ma (Scott, 2014).

Systematic classification of planktic Foraminifera by Huber and Leckie (2011), in which full references to suprageneric classification are provided.

Supergroup Rhizaria Cavalier-Smith, 2002
Class Foraminifera d'Orbigny, 1826
Order Globigerinina Delage and Hérouard, 1896
Family Hedbergellidae Loeblich and Tappan, 1961
Subfamily Hedbergellinae Loeblich and Tappan, 1961
Genus *Microhedbergella* Huber and Leckie, 2011
Microhedbergella pseudodelrioensis Huber and Leckie, 2011
Figure 3, 13

Remarks. The genus *Microhedbergella* (Huber and Leckie, 2011) has a low trochospiral test with globular chambers and thin, microperforated walls, and smooth exterior walls or with few low pustules (Huber and Leckie, 2011). The specimens in the Cerro La Puerta Member (sample 2-19-20-8, 312-319 m) have a diameter of 230 microns and a thickness of 108 microns, a test thickness/diameter ratio of 0.47. This species ranges from the lower Albian *Microhedbergella rischi* Zone into the upper Albian *Ticinella primula* Zone in the North and South Atlantic (Huber and Leckie, 2011). This species has been reported in Lower Cretaceous strata in Mexico and Texas as *Globigerina delrioensis* (Longoria, 1984; Scott, 1990; Scott and Warzeski, 1993); considering revised systematics of Huber and Leckie (2011), these identifications need to be reevaluated. It is present in forereef and basin facies downslope of the Comanche Shelf margin in the Albian Salmon Peak Formation (Scott, 1990) and in the Aptian-lower Albian upper Tamaulipas Formation and equivalent units in eastern Mexico (Longoria, 1984).

Megafossils

Bivalve systematic classification by Carter *et al.* (2011), in which full references to suprageneric classification are provided.

Order Hippuritoida Newell, 1965
Superfamily Radiolitoidea d'Orbigny, 1847
Family Caprinidae d'Orbigny, 1847
Subfamily Caprinuloideinae Damestoy, 1971
Genus *Coalcomana* Coogan, 1973
Figure 3, 17

Remarks. Several wall fragments bear a single row of large oval to tear-drop-shaped pallial canals, and the septa divide forming small oval canals on the outer wall margin typical of this lower Albian genus. These specimens are in thin sections of the Cerro La Espina Member in the Arizpe section. This genus is common in the lower Albian Glen Rose Formation in Texas (Scott, 2002; Scott and Filkorn, 2007); it is present in the Alisitos Formation, Baja California (Madhavaraju *et al.*, 2021) and in the Mural Limestone in Sonora (Gonzalez-León *et al.*, 2008; Madhavaraju *et al.*, 2018; Scott and Warzeski, 1993). *Coalcomana* *ramosa* (Boehm) in the Glen Rose Formation has a short range of 111.55–111.26 Ma (Scott, 2014).

Suprageneric classification of Echinoidea by Fischer (1966) modified by Kroh and Moori (2021).

Phylum Echinodermata Bruguière, 1791
Class Echinoidea Leske, 1778
Order Spatangoida Agassiz, 1840
Suborder Hemiasterina A.G. Fisher, 1966
Family Toxasteridae Lambert, 1920
Genus *Pliotoxaster* Pomel. 1883
Pliotoxaster comanchei (Clark in Clark and Twitchell, 1915)

Remarks. Clark (1915) and Cook (1946) placed this species in the genus *Hemiaster;* Smith and Rader (2009) ascribed this species to *Pliotoxaster*. P. *comanchei* is common in the lower member and basal upper member of the lower Albian Glen Rose Formation in central Texas. It is in the rudist bioherm interval and in the maximum flooding *Salenia* bed (Smith and Rader, 2009). Nieto-López *et al.* (2006) report other Lower and Upper Cretaceous species in Mexico.

REFERENCES

Alsleben, H., Wetmore, P.H., Gehrels, G.E., Paterson, S.R., 2012, Detrital zircon ages in Paleozoic and Mesozoic basement assemblages of the Peninsular Ranges batholith, Baja California, Mexico: Constraints for depositional ages and provenance: International Geology Review, 54(1), 93-110, doi:10.1080/00206814.2010.509158.

Anderson, T.H., Rodríguez-Castañeda, J.L., Silver, L.T., 2005, Jurassic rocks in Sonora, Mexico: Relations to the Mojave-Sonora megashear and its inferred northwestward extension, *in* Anderson, T.H., Nourse, J.A., McKee, J.W., Steiner, M.B. (eds.), The Mojave-Sonora megashear hypothesis: Development, assessment, and alternatives: Geological Society of America Special Paper 393, 51-95, https://doi.org /10.1130/0-8137-2393-0.51.

Arnaud-Vanneau, A., Peybernès, B., 1978, Les représentants éocrétacés du genre Nautiloculina Mohler, 1938 (Foraminifera, Fam. Lituolidae?) dans les chaines subalpines septentrionales (Vercors) et les pyrénées Franco-Espagnoles: Geobios 11(1), 67-81, https://doi.org/10.1016/s0016-6995(78)80019-9.

Arnaud-Vanneau, A., Premoli Silva, I., 1995, Biostratigraphy and systematic description of benthic foraminifers from mid-Cretaceous shallow water carbonate platform sediments at sites 878 and 879 (MIT and Takuyo-Daisan Guyots), *in* Haggerty, J.A., Premoli Silva, I., Rack, F., McNutt, M.K. (eds.), Proceedings of the Ocean Drilling Program, Scientific Results, 144, 199-219.

Arnaud-Vanneau, A., Sliter, W., 1995, Early Cretaceous Shallow-Water Benthic Foraminifers and Fecal Pellets from Leg 143 Compared with Coeval Faunas from the Pacific Basin, Central America, and the Tethys: Proceedings of the Ocean Drilling Program, Scientific Results, 143, https://doi.org/10.2973/odp.proc.sr.143.252.1995.

Arvizu, H.E., Iriondo, A., 2015, Control temporal y geología del magmatismo Permo-Triásico en Sierra Los Tanques, NW Sonora, México: Evidencia del inicio del arco magmático cordillerano en el SW de Laurencia: Boletín de la Sociedad Geológica Mexicana, 67, 545-586, http://dx.doi.org/10.18268/BSGM2015v67n3a16.

Balgord, E.A., Yonkee, W.A., Wells, M.L., Gentry, A., Laskowski, A.K., 2021, Arc tempos, tectonic styles, and sedimentation patterns during evolution of the North American Cordillera: Constraints from the retroarc detrital zircon archive: Earth-Science Reviews, 216, 103557, https://doi.org/10.1016/j.earscirev.2021.103557.

Barnard, T., Banner, F.T., 1980, The Ataxophragmiidae of England: Part I, Albian-Cenomanian *Arenobulimina* and *Crenaverneuilina*: Revista Española de Micropaleontología, 12, 383-430.

Bassett, K.N., Busby, C.J., 2005, Tectonic setting of the Glance Conglomerate along the Sawmill Canyon fault zone, southern Arizona: A sequence analysis of an intra-arc strike-slip basin, *in* Anderson, T.H., Nourse, J.A., McKee, J.W., Steiner, M.B. (eds.), The Mojave-Sonora megashear hypothesis: Development, assessment, and alternatives: Geological Society of America Special Paper 393, 377-400, doi: 10.1130/2005.2393(14).

Blichert-Toft, J., Albarède, F., 1997, The Lu-Hf isotope geochemistry of chondrites and the evolution of the mantle-crust system: Earth and Planetary Science Letters, 148(1-2), 243-258, https://doi.org/10.1016/S0012-821X(97)00040-X.

Bolze, J., Colom, G., Sigal, J., 1959, Présence du genre *Colomiella* Bonet, 1956 en Tunisie. Les Calpionnelles post-Néocomiennes: Revue Micropaléontologie, 2, 50-52.

Bonet, F., 1956, Zonificación microfaunística de las calizas cretácicas del Este de México: Boletín Asociación Mexicana del Geólogos Petroleros, 8, 389-508.

BouDagher-Fadel, M.K., 2018, Evolution and Geological Significance of Larger Benthic Foraminifera: London, UCL Press, Second edition, https:// doi.org/ 10.14324/ 111.9781911576938.

Bouvier, A., Vervoort, J., Patchett, J., 2008, The Lu-Hf and Sm-Nd isotopic composition of CHUR: Constraints from unequilibrated chondrites and implications for the bulk composition of terrestrial planets: Earth and Planetary Science Letters, 273, 48-57, https://doi.org/10.1016/j.epsl.2008.06.010.

Bralower, T.J., CoBabe, E., Clement, B., Sliter,W.V., Osburn, C.L., Longoria, J., 1999, The record of global change in Mid-Cretaceous (Barremian-Albian) sections from the Sierra Madre, northeastern Mexico: Journal of Foraminiferal Research, 29, 418-437.

Busby, C.J., Morris, R.A., DeBari, S.M., Medynski, S., Putirka, K., Andrews, G.D.M., Schmitt, A.K., Brown, S.R., 2023, Geology of a Large Intact Extensional Oceanic Arc Crustal Section with Superior Exposures: Cretaceous Alisitos Arc, Baja California (Mexico): Geological Society of America Special Paper 560, 1-105, https://doi.org/10.1130/2023.2560(01).

Busby-Spera, C.J., 1988, Speculative tectonic model for the early Mesozoic arc of the southwest Cordilleran United States: Geology, 16, 1121-1125, doi: https://doi.org/10.1130/0091-7613(1988)016<1121:STMFTE>2.3.CO;2.

Byrum, S., Lieberman, B.S., 2021, Phylogeny and biogeography of some Cretaceous spatangoid echinoids with special emphasis on taxa from the Western Interior Seaway: Journal of Paleontology, 95, 613-623, doi: 10.1017/jpa.2020.102.

Calvez, H., 1986, Deux Foraminifères nouveaux de l'Albien calcaire des Pyrénées franco-espagnoles: *Pseudonummoloculina aurigerica* n. gen., n. sp. et *Dobrogelina*? *angulata* n. sp.: Benthos '86, Résumés Abstracts, Genève, Muséum d'Histoire Naturelle, p. 31.

Cantú Chapa, C.M., Sandoval Silva, R., Arenas Partida, R., 1985, Evolución sedimentaria del Cretácico Inferior en el norte de México: Revista del Instituto Mexicano del Petróleo, XVII(2), 14-37.

Chu, N.C., Taylor, R.N., Chavagnac, V., Nesbitt, R.W., Boella, R.M., Milton, J.A., German, C.R., Bayon, G., Burton, K., 2002, Hf isotope ratio analysis using multi-collector inductively coupled plasma mass spectrometry: An evaluation of isobaric interference corrections: Journal of Analytical Atomic Spectrometry, 17, 1567-1574, https://doi.org/10.1039/b206707b.

Clark, W.B., Twitchell, M.W., 1915, The Mesozoic and Cenozoic Echinodermata of the United States: U.S. Geological Survey Monograph, 54, 341 pp.

Conkin, J.E., Conkin, B.M., 1958, Revision of the genus *Nummoloculina* and emendation of *Nummoloculina heimi* Bonet: Micropaleontology, 4, 149-150.

Contreras-López, M., Delgado-Argote, L.A., Weber, B., Torres-Carrillo, X.G., Frei, D., Gómez-Alvarez, D.K., Tazzo-Rangel, M.D., Schmitt, A.K., 2021, Geochemistry, UPb geochronology, and Sr-Nd-Hf isotope systematics of a SW-NE transect in the southern Peninsular Ranges batholith, Mexico: Cretaceous magmatism developed on a juvenile island-arc crust: Lithos, v. 400–401, https://doi.org/10.1016/j.lithos.2021.106375.

Coogan, A.H., 1973, Nuevos rudistas del Albiano y Cenomaniano de Mexico y del sur de Texas: Revista del Instituto Mexicano del Petróleo, 5, 51-83.

Cooke, C.W., 1946, Comanche echinoids: Journal of Paleontology 23, 193-237.

Cragin, F.W., 1893, A contribution to the invertebrate paleontology of the Texas Cretaceous: Geological Survey of Texas, 4th Annual Report, Pt. 2, 141-294.

Cushman, J.A., Applin, E.R., 1947, Two new species of lower Cretaceous foraminifera from Florida: Contributions from the Cushman Laboratory for Foraminiferal Research, 23, 29-30.

d'Orbigny, A.D., 1839, Foraminifères, *in* de la Sagra, R. (ed.), Histoire physique, politique et naturelle de l'île de Cuba: Paris, Arthus Bertrand, tome 8.

Dickinson, W.R., 1985, Interpreting provenance from detrital modes of sandstones, *in* Zuffa, G.G. (ed.), Provenance of Arenites: D. Reidel, Dordrecht, Netherlands, 333-361, https://doi.org/10.1007/978-94-017-2809-6_15.

Dickinson, W.R., Klute, M.A., Swift, P.A., 1986, The Bisbee basin and its bearing on late Mesozoic paleogeographic and paleotectonic relations between the Cordilleran and Caribbean regions, *in* Abbott, P.L., (ed.), Cretaceous stratigraphy, western North America: Los Angeles, Pacific Section, Society of Economic Mineralogists and Paleontologists, Book 46, 51-62.

Filkorn, H.F., Scott, R.W., 2011, Microfossils, paleoenvironments and biostratigraphy of the Mal Paso Formation (Cretaceous, Upper Albian), State of Guerrero, Mexico: Revista Mexicana de Ciencias Geológicas, 28, 175-191.

Fischer, A.G., 1966, Spatangoids, *in* Durham, J.W. and 15 others (eds.), Part U Echinodermata 3, Asterozoa-Echinozoa, vol 2. Treatise on Invertebrate Paleontology: Geological Society of America and University of Kansas Press, p. U543–U628.

Fisher, C.M., Hanchar, J.M., Samson, S.D., Dhuime, B., Blichert-Toft, J., Vervoort, J.D., Lam, R., 2011, Synthetic zircon doped with hafnium and rare earth elements: A reference material for in situ hafnium isotope analysis: Chemical Geology, 286, 32-47, https://doi.org/10.1016/j.chemgeo.2011.04.013.

Fisher, C.M., Vervoort, J.D., Hanchar, J.M., 2014, Guidelines for reporting zircon Hf isotopic data by LA-MC-ICPMS and potential pitfalls in the interpretation of these data: Chemical Geology, 363, 125-133.

Gehrels, G., Pecha, M., 2014, Detrital zircon U-Pb geochronology and Hf isotope geochemistry of Paleozoic and Triassic passive margin strata of western North America: Geosphere, 10, 49-65, https://doi.org/10.1130/GES00889.1.

Gehrels, G.E., Stewart, J.H., 1998, Detrital zircon U-Pb geochronology of Cambrian to Triassic miogeoclinal and eugeoclinal strata of Sonora, Mexico: Journal of Geophysical Research Solid Earth, 103, B2, 2471-2487, https://doi.org/10.1029/97JB03251.

Gehrels, G.E., Blakey, R., Karlstrom, K.E., Timmons, J.M., Dickinson, W.R., Pecha, M., 2011, Detrital zircon U-Pb geochronology of Paleozoic strata in the Grand Canyon, AZ: Lithosphere 3, 183-200, doi: https://doi.org/10.1130/L121.1.

Gerdes, A., Zeh, A., 2009, Zircon formation versus zircon alteration - New insights from combined U–Pb and Lu–Hf in-situ LA-ICP-MS analyses, and consequences for the interpretation of Archean zircon from the Central Zone of the Limpopo Belt: Chemical Geology, 261, 230-243.

González Gallegos, A., Morales Morales, H., Orantes Contreras, V., 2003, Carta geológico minera Arizpe H12-B73 Sonora: Servicio Geológico Mexicano, Secretaría de Economía, escala 1:50,000, https://mapserver.sgm.gob.mx/Cartas_Online/geologia/356_H12-B73_GM.pdf.

González-León, C., 1988, Estratigrafía y Geología estructural de las rocas sedimentarias Cretácicas del área de Lampazos, Sonora: Universidad Nacional Autónona de México, Instituto de Geología, Revista, 7, 148-162.

González-León, C., Lucas, S.G., 1995. Stratigraphy and paleontology of the Early Cretaceous Cerro de Oro Formation, central Sonora, *in* Jacques-Ayala, C., González- León, C.M., Roldán-Quintana, J. (eds.), Studies on the Mesozoic of Sonora and Adjacent Areas: Geological Society of America, Special Paper 301, 41-47.

González León, C.M., 1978, Geología del área de Arizpe, Sonora centro septentrional: Sonora, Universidad de Sonora, Departamento de Geología, professional thesis, 73 pp.

González León, C.M., McIntosh, W.C., Lozano-Santacruz, R., Valencia-Moreno, M., Amaya-Martínez, R., Rodríguez-Castañeda, J.L., 2000, Cretaceous and Tertiary sedimentary, magmatic, and tectonic evolution of north-central Sonora (Arizpe and Bacanuchi Quadrangles), northwest Mexico: Geological Society of America Bulletin, 112(4), 600-610, doi: https://doi.org/10.1130/0016-7606(2000)112<600:CATSMA>2.0.CO;2.

González-León, C.M., Scott, R.W., Löser, H., Lawton, T.F., Robert, E., Valencia, V.A., 2008, Upper Aptian-Lower Albian Mural Formation: stratigraphy, biostratigraphy and depositional cycles on the Sonoran Shelf, northern Mexico: Cretaceous Research, 29, 249-266.

González-León, C.M., Solari, L., Solé, J., Ducea, M.N., Lawton, T.F., Bernal, J.P., González Becuar, E., Gray, F., López Martínez, M., Lozano Santacruz, R., 2011, Stratigraphy, geochronology and geochemistry of the Laramide magmatic arc in north-central Sonora, Mexico: Geosphere, 7(6), 1392-1418, doi: 10.1130/GES00679.1.

González-León, C.M., Madhavaraju, J., Ramírez Montoya, E., Solari, L.A., Villanueva-Amadoz, U., Monreal, R., Sánchez Medrano, P.A., 2020, Stratigraphy, detrital zircon geochronology and provenance of the Morita formation (Bisbee Group) in northeastern Sonora, Mexico: Journal of South American Earth Sciences, 103, https://doi.org/10.1016/j.jsames.2020.102761.

González-León, C.M., Vázquez-Salazar, M., Sánchez Navarro, T., Solari, L.A., Nourse, J.A., Del Rio-Salas, R., Lozano-Santacruz, R., Pérez Arvizu, O., Valenzuela Chacón, J.C., 2021, Geology and geochronology of the Jurassic magmatic arc in the Magdalena quadrangle, north-central Sonora, Mexico: Journal of South American Earth Sciences, 108, https://doi.org/10.1016/j.jsames.2020.103055.

Griffin, W., Wang, X., Jackson, S., Pearson, N., O'Reilly, S.Y., Xu, X., Zhou, X., 2002, Zircon chemistry and magma mixing, SE China: *In-situ* analysis of Hf isotopes, Tonglu and Pingtan igneous complexes: Lithos, 61, 237-269, https://doi.org/10.1016/S0024-4937(02)00082-8.

Grijalva-Noriega, F.J., 1996, Cintura Formation – an Early Cretaceous deltaic system in northeastern Sonora, Mexico: Revista Mexicana de Ciencias Geológicas, 13, 129-139.

Haxel, G.B., Wright, J.E., Riggs, N.R., Tosdal, R.M., May, D.J., 2005, Middle Jurassic Topawa Group, Baboquivari Mountains, south-central Arizona: volcanic and sedimentary record of deep basins within the Jurassic magmatic arc, *in* Anderson, T.H., Nourse, J.A., McKee, J.W., Steiner, M.B. (eds.), The Mojave-Sonora Megashear Hypothesis: Development, Assessment, and Alternatives: Geological Society of America Special Paper 393, 329-357, https://doi.org/10.1130/0-8137-2393-0.329.

Haxel, G.B., May, D.J., Anderson, T.H., Tosdal, R.M., Wright, J.E., 2008a, Geology and geochemistry of Jurassic plutonic rocks, Baboquivari Mountains, south-central Arizona, *in* Spencer, J.E., Titley, S.R. (eds.), Ores and Orogenesis: Circum-Pacific Tectonics, Geologic Evolution, and Ore Deposits: Arizona Geological Society Digest, 22, 496-515.

Haxel, G.B., Anderson, T.H., Briskey, J.A., Tosdal, R.M., Wright, J.E., May, D.J., 2008b, Late Jurassic igneous rocks in south-central Arizona and north central Sonora: Magmatic accompaniment of crustal extension, *in* Spencer, J.E., Titley, S.R. (eds.), Ores and Orogenesis: Circum-Pacific Tectonics, Geologic Evolution, and Ore Deposits: Arizona Geological Society Digest, 22, 333-355.

Hayes, P.T., 1970, Cretaceous Paleogeography of Southeastern Arizon: Geological Survey Professional Paper 658-B, 42 p.

Heilprin, A., 1891, The geology and paleontology of the Cretaceous deposits of Mexico: Procedings of the Academy of Natural Sciences, Philadelphia, 1890, 445-469.

Henson, F.R.S., 1948, New trochamminidae and verneuilinidae from the middle east: Annals and Magazine of Natural History, 11, 605-636.

Howard, K. A., Shaw, S.E., Allen, C.M., 2023, Magmatic record of changing Cordilleran plate-boundary conditionsInsights from Lu-Hf isotopes in the Mojave Desert: Geosphere, 19, 1-18. doi: https://doi.org/10.1130/GES02438.1.

Huber, B.T., Leckie, R.M., 2011, Planktic Foraminiferal species turnover across deep-sea Aptian/Albian boundary sections: Journal of Foraminiferal Research, 41, 53-95.

INEGI (Instituto Nacional de Estadística Geografía e Informática), 2001, Carta Topográfica Arizpe H12B73: Mexico, scale 1:50,000, 1 map.

Jacques-Ayala, C., 1995, Paleogeography and provenance of the Lower Cretaceous Bisbee Group in the Caborca–Santa Ana area, northwestern Sonora, *in* Jacques- Ayala, C., González-León, C.M., Roldán-Quintana, J. (eds.), Studies on the Mesozoic of Sonora and Adjacent Areas: Geological Society of America Special Paper 301, 79-98.

Kroh, A., Mooi, R., 2021, World Echinoidea Database. Pliotoxaster Fourtau, 1908 †. Accessed at: http://www.marinespecies.org/Echinoidea/aphia.php?p=taxdetails&id=512789 on 2021-07-22.

Lackey, J.S., Cecil, M.R., Windham, C.J., Frazer, R.E., Bindeman, I.N., Gehrels, G.E., 2012, The Fine Gold Intrusive Suite: The roles of basement terranes and magma source development in the Early Cretaceous Sierra Nevada batholith: Geosphere, 8, 292-313, doi: https://doi.org/10.1130/GES00745.1.

Lawton, T.F., McMillan, N.J., 1999, Arc abandonment as a cause for passive continental rifting: Comparison of the Jurassic Mexican Borderland rift and the Cenozoic Rio Grande rift: Geology, 27, 779-782, https:// doi .org/10.1130/0091-7613(1999)027<0779:AAAAC F>2.3.CO;2.

Lawton, T.F., González León, C.M., Lucas, S.G., Scott, R.W., 2004, Stratigraphy and sedimentology of the upper Aptian-upper Albian Mural Limestone (Bisbee Group) in northern Sonora, Mexico: Cretaceous Research, 25, 43-60.

Lawton, T.F., Amato, J.M., Machin, S.E.K., Gilbert, J.C., Lucas, S.G., 2020, Transition from Late Jurassic rifting to middle Cretaceous dynamic foreland, southwestern U.S. and northwestern Mexico: Geological Sociery of America Bulletin, 132, 2489-2516, doi: https://doi.org/10.1130/B35433.1.

Loeblich, A.R., Jr., Tappan, H., 1988, Foraminiferal genera and their classification: New York, Van Nostrand Reinhold Company, v. 2, 847 pp.

Longoria, J.F., 1984, Cretaceous biochronology from the Gulf of Mexico region based on planktonic microfossils: Micropaleontology, 30, 225-242.

Löser, H., 2011, The Cretaceous corals from the Bisbee Group (Sonora; late Barremian - early Albian): Introduction and family Aulastraeoporidae: Revista Mexicana de Ciencias Geológicas, 28, 254-261.

Luperto Sinni, E., 1979, I microfossili del livello a *Palorbitolina lenticularis* delle Murge baresi: Rivista Italiana di Paleontologia e Stratigrafia, 85, 411-480.

Luperto Sinni, E., Masse, J. P., 1993, Specie nuove di foraminiferi bentonici dell'Aptiano inferiore carbonatico delle Murge (Italia Meridionale): Rivista Italiana di Paleontologia e Stratigrafia 99, 213-224, https://doi.org/10.13130/2039-4942/8907.

Madhavaraju, J., Scott, R.W., Selvaraj, K., Lee, Y.I., Löser, H., 2021, Isotopic chemostratigraphy and biostratigraphy of Lower Cretaceous Alisitos Formation (Punta China section), Baja California, Mexico: Geological Journal, 56(5), 2550-2570.

Madhavaraju, J., Yong, I.L. Lee, Scott, R.W., González-León, C.M., Jenkyns, H.C., Saucedo-Samaniego, J.C., Ramasamy. S., 2018, High-resolution isotopic study of Lower Cretaceous Mural Formation (Cerro Pimas column), Sonora, México: Implications for early Albian oceanic anoxic events: Journal of South American Earth Sciences, 82, 329-345.

Magniez, E., 1972, *Spiroplectamminoides*, nouveau genre de Foraminifères des Formations Para-Urgoniennes Cantabriques (Espagne): Revista Española de Micropaleontologia, numero Extraordinario, XXX Anniversario Empresso Nacional Adaro, Madrid, 179-198.

Martini, M., Ortega-Gutiérrez, F., 2018, Tectono-stratigraphic evolution of Eastern Mexico during the break-up of Pangea: A review: Earth-Science Reviews, 183, 38-55.

Mauel, D. J., Lawton, T. F., González-León, C. M., Iriondo, A., Amato, J. M., 2011, Stratigraphy and age of Upper Jurassic strata in north-central Sonora, Mexico: Southwestern Laurentian record of crustal extension and tectonic transition: Geosphere, 7(2), 390-414, doi: 10.1130/GES00600.1.

Maync, W., 1955, *Coskinolina sunnilandensis* n. sp. a Lower Cretaceous (Urgonian- Albian) species: Contributions from the Cushman Foundation for Foraminiferal Research 6, part 3, 105-111.

McKee, M.B., Anderson, T.H., 1998, Mass-gravity deposits and structures in the Lower Cretaceous of Sonora, Mexico: Geological Society of America Bulletin, 110(12), 1516-1529, doi: 10.1130/0016-7606(1998)110<1516:MGDASI>2.3.CO;2.

McKee, J.W., McKee, M.B., Anderson, T.H., 2005, Mesozoic basin formation, mass-gravity sedimentation, and inversion in northeastern Sonora and southeastern Arizona, *in* Anderson, T.H., Nourse, J.A., McKee, J.W., and Steiner, M.B. (eds.), The Mojave-Sonora megashear hypothesis: Development, assessment, and alternatives: Geological Society of America Special Paper 393, 481-507, doi: 10.1130/2005.2393(18).

Monreal, R., Longoria, J.F., 2000, Stratigraphy and structure of the Lower Cretaceous of Lampazos, Sonora, (northwest Mexico) and its relationship to the Gulf Coast succession: American Association of Petroleum Geologist Bulletin 84, 1811-1831.

Monreal, R., Valenzuela, M., González-León, C., 1994, A revision of the stratigraphic nomenclature for the Cretaceous of northern Sonora, and some paleogeographic implications: Universidad de Sonora, Departamento Geología Boletin, 11, 171-190.

Moullade, M., 1965, Contribution au problème de la classification des Orbitolinidae (Foraminferida, Lituolacea): Comptes Rendus Hebdomadaires des Séances, Académie des Sciences, 260, 4031-4034.

Neumann, M., 1965, Contribution à l'étude de quelques lituolidés du Cénomanien de l'Ile Madame (Charente-Maritime): Revue de Micropaléontologie, 8, 90-95.

Nieto-López, I., García-Barrera, P., 2006, Cretaceous Echinoids of Mexico, *in* Vega, F.J., Nyborg, T.G., Perrilliat, M.C., Montellano-Ballesteros, M., Cevallos-Ferriz, S.R.S., Quiroz-Barroso, S.A. (eds.), Studies on Mexican Paleontology: Topics in Geobiology, 24, 101-113.

Omaña, L., López-Doncel, R., Torres, J.R., Alencaster, G., López-Caballero, I., 2019, Mid-late Cenomanian larger benthic foraminifers from the El Abra Formation W Valles-San Luis Potosi Platform, central-eastern Mexico: Taxonomy, biostratigraphy and paleoenvironmental implications: Boletín de la Sociedad Geológica Mexicana, 71, 691-725; https://doi.org/10.18268/BSGM2019v71n3a5

Omara, S., 1956, New foraminifera from the Cenomanian of Sinai, Egypt: Journal of Paleontology, 30, 883-890.

Ortega-Obregón, C., Solari, L.A., Gómez-Tuena, A., Elías-Herrera, M., Ortega-Gutiérrez, F., Macías-Romo, C., 2014, Permian–Carboniferous arc magmatism in southern Mexico: U-Pb dating, trace element and Hf isotopic evidence on zircons of earliest subduction beneath the western margin of Gondwana: International Journal of Earth Sciences, 103, 1287-1300, https://doi.org/10.1007/s00531-013-0933-1.

Ortega-Rivera, A., 2003, Geochronological constraints on the tectonic history of the Peninsular Ranges batholith of Alta and Baja California: Tectonic implications for western México, *in* Johnson, S.E., Paterson, S.R., Fletcher, J.M., Girty, G.H., Kimbrough, D.L., Martín-Barajas, A. (eds.), Tectonic evolution of northwestern México and the southwestern USA: Boulder, Colorado, Geological Society of America Special Paper 374, 297-335, DOI: https://doi.org/10.1130/0-8137-2374-4.297.

Patchett, P.J., Tatsumoto, M., 1981, Lu/Hf in chondrites and definition of chondritic hafnium growth [abs.]: Lunar and Planetary Science Institute, XII, 822-824.

Paton, C., Hellstrom, J., Paul, B., Woodhead, J., Hergt, J., 2011, Iolite: Freeware for the visualisation and processing of mass spectrometric data: Journal of Analytical Atomic Spectrometry, 26, 2508-2518.

Payne, J.L., Pearson, N.J., Grant, K.J., Halverson, G.P., 2013, Reassessment of relative oxide formation rates and molecular interferences on in situ lutetium–hafnium analysis with laser ablation MC-ICP-MS: Journal of Analytical Atomic Spectrometry, 28, 1068-1079.

Pecha, M.E., Blum, M.D., Gehrels, G.E., Sundell, K.E., Karlstrom, K.E., Gonzales, D.A., Malone, D.H., Mahoney, J.B., 2022, Linking the Gulf of Mexico and Coast Mountains batholith during late Paleocene time: Insights from Hf isotopes in detrital zircons, *in* Craddock, J.P., Malone, D.H., Foreman, B.Z., Konstantinou, A. (eds.), Tectonic Evolution of the Sevier-Laramide Hinterland, Thrust Belt, and Foreland, and Postorogenic Slab Rollback (180–20 Ma): Geological Society of America Special Paper 555, 265-292, https://doi.org/10.1130/2021.2555(10).

Peryam, T.C., Lawton, T.F., Amato, J.M., González-León, C.M., Mauel, D., 2012, Lower Cretaceous strata of the Sonora Bisbee Basin: A record of the tectonomagmatic evolution of northwestern Mexico: Geological Society of America Bulletin, 124, 532-548.

Petrus, J.A., Kamber, B.S., 2012, VizualAge: a novelapproach to laser ablation ICP-MS U–Pb geochronol-ogy data reduction.Geostandards and GeoanalyticalResearch,36, 247-270, https://doi.org/10.1111/j.1751-908X.2012.00158.x

Pomel, A., 1883, Classification méthodique et genre des échinides vivants et fossiles. Alger, A. Jourdan, 132 pp., https://doi.org/10.5962/bhl.title.11272

Premo, W.R., Morton, D.M., Wooden, J.L., Fanning, C.M., 2014, U-Pb zircon geochronology of plutonism in the northern Peninsular Ranges batholith, southern California: Implications for the Late Cretaceous tectonic evolution of southern California, *in* Morton, D.M., and Miller, F.K. (eds.), Peninsular Ranges Batholith, Baja California and Southern

California: Geological Society of America Memoir 211, 145-180, doi:10.1130/2014.1211(04).
Radoičić, R., 1959, Nekoliko problematičnih mikrofosila iz dinarske krede (Some problematic microfossils from the Dinarian Cretaceous): Bulletin Service Géologie i Géophysics Republic of Serbie 17, 87-92
Ransome, F.L., 1904, Geology and mineral deposits of the Bisbee Quadrangle, Arizona: U.S. Geological Survey Prof.essional Paper 21, 167 pp.
Roemer, F., 1849, Texas, mit besonderer Rüchsicht auf deutsche Auswanderung und die physichen Verhaltnisse des Landes: Bonn, Adolph Marcus, 464 pp.
Saucedo-Samaniego, J. C., Madhavaraju, J., Sial, A.N., Monreal, R., Scott, R.W., Perez-Arvizu, O., 2021, Upper Aptian-Lower Albian seawater composition and OAEs: Geochemistry of Agua Salada and Lampazos Formations, Sonora, Mexico : Journal of South American Earth Sciences, 109; https://doi.org/10.1016/j.jsames.2021.103193.
Scherer, E., Münker, C., Mezger, K., 2001, Calibration of the lutetiumhafnium clock: Science, 293, 683-687, doi: 10.1126/science.1061372, PMID: 11474108.
Schlagintweit, F., Scott, R.W., 2015, *Voloshinoides sonorensis* n. sp. (Cretaceous benthic foraminifera): a potential lower Albian marker of shallow-water carbonates in northern Mexico: Cretaceous Research, 55, 206-212, DOI: 10.1016/j.cretres.2014.10.002.
Schroeder, R., 1962, Orbitolinen des Cenomans Südwesteuropas: Paläontologische Zeitschrift, 36, 171-202.
Schwartz, T.M., Surpless, K.D., Colgan, J.P., Johnstone, S.A., Holm-Denoma, C.S., 2021, Detrital zircon record of magmatism and sediment dispersal across the North American Cordilleran arc system (28–48°N): Earth-Science Reviews, 220, 103734, https://doi.org/10.1016/j.earscirev.2021.103734.
Scott, R.W., 1990, Models and stratigraphy of Mid-Cretaceous reef communities, Gulf of Mexico: SEPM (Society for Sedimentary Geology), Concepts in Sedimentology and Paleontology, 2, 102 pp.
Scott, R.W., 2007, Late Aptian-Early Albian bivalves of the Comanchean and Sonoran shelves: New Mexico Museum of Natural History and Science Bulletin 39, 7-39.
Scott, R.W., 2014, Cretaceous chronostratigraphic database: construction and applications: Carnets de Geologie, 14(2), 15-37.
Scott, R.W., González-León, C., 1991, Paleontology and biostratigraphy of Cretaceous rocks, Lampazos area, Sonora, Mexico, *in* Pérez-Segura, E., Jacques-Ayala, C. (eds.), Studies of Sonoran geology: Geological Society of America Special Paper 254, doi: https://doi.org/10.1130/SPE254-p51.
Scott, R.W., Warzeski, E.R., 1993, An Aptian-Albian shelf ramp, Arizona and Sonora, *in* Simo, J.A.T., Scott, R.W., Masse, J.-P. (eds.), Cretaceous Carbonate Platforms: American Association of Petroleum Geologists, Memoir 56, 71-79.
Scott, R.W., González-León, C.M., Lawton, T.F., Madhavaraju, J., Saucedo-Samaniego, J.C., Sierra Rojas, M.I., en prensa 2023, Aptian-Albian Sequence Stratigraphy, Biostratigraphy, Chemostratigraphy, and Chronostratigraphy: Sonoran Shelf and Tamaulipas Basin, Mexico: Cretaceous Research, 105776, https://doi.org/10.1016/j.cretres.2023.105776.
Sharman, G.R., Graham, S.A., Grove, M., Kimbrough, D.L., Wright; J.E., 2015, Detrital zircon provenance of the Late Cretaceous–Eocene California forearc: Influence of Laramide low-angle subduction on sediment dispersal and paleogeography: Geological Society of America Bulletin, 127(1-2), 38-60, doi: https://doi.org/10.1130/B31065.1.
Shaw, S.E., Todd, V.R., Grove, M., 2003, Jurassic peraluminous gneissic granites in the axial zone of the Peninsular Ranges, southern California, *in* Johnson, S.E., Paterson, S.R., Fletcher, J.M., Girty, G.H., Kimbrough, D.L., Martín-Barajas, A. (eds.), Tectonic Evolution of Northwestern Mexico and the Southwestern USA: Geological Society of America Special Paper 374, 157-184.
Shaw, S.E., Todd, V.R., Kimbrough, D.L., Pearson, N.J., 2014, A west-to-east geologic transect across the Peninsular Ranges batholith, San Diego County, California: Zircon 176Hf/177Hf evidence for the mixing of crustal- and mantle-derived magmas, and comparisons with the Sierra Nevada batholith, *in* Morton, D.M., Miller, F.K. (eds.), Peninsular Ranges Batholith, Baja California and Southern California: Geological Society of America Memoir 211, 499-536, doi:10.1130/2014.1211(15).
Skelton, P.W.,1978, The evolution of functional design in rudists (Hippuritacea) and its taxonomic implications: Philosophical Transactions of the Royal Society of London, B 284, 305-318.
Skelton, P.W., Masse, J.-P., 1998, Revision of the Lower Cretaceous rudist genera *Pachytraga* Paquier and *Retha* Cox (Bivalvia: Hippuritacea), and the origins of the Caprinidae: Géobios, Mémoire spécial 22, 331-370.
Sláma, J., Košler, J., Condon, D., Crowley, J., Gerdes, A., Hanchar, J., Horstwood, M., Morris, G., Nasdala, L., Norberg, N., Schaltegger, U., Schoene, B., Tubrett, M., Whitehouse, M.J., 2008, Plešovice zircon — A new natural reference material for U–Pb and Hf isotopic microanalysis: Chemical Geology, 249, 1-35, https://doi.org/ 10.1016/j.chemgeo.2007.11.005.
Smith, A.B., Rader, W.L., 2009. Echinoid diversity, preservation potential and sequence stratigraphical cycles in the Glen Rose Formation (early Albian, Early Cretaceous), Texas, USA: Palaeobiodiversity Palaeoenvironments, 89, 7-52, DOI 10.1007/s12549-009-0002-8.
Solari, L., González-León, C., Ortega-Obregón, C., Valencia-Moreno, M., Rascón- Heimpel, M.A., 2018, The Proterozoic of NW Mexico revisited: U–Pb geochronology and Hf isotopes of Sonoran rocks and their tectonic implications: International Journal of Earth Sciences, 107, 845-861.
Stanton, T.W., 1947, Studies of some Comanche Pelecypods and Gastropods: U.S. Geological Survey, Professional Paper 211, 256 pp., 66 pl.
Stewart, J.H., Gehrels, G.E., Barth, A.P., Link, P.K., Christie-Blick, N., Wrucke, C.T., 2001, Detrital zircon provenance of Mesoproterozoic to Cambrian arenites in the western United States and northwestern Mexico: Geological Society of America Bulletin, 113, 1343-1356- doi: https://doi.org/10.1130/0016-7606(2001)113<1343:DZPOMT>2.0.CO;2.
Surpless, K.D., Gulliver, K.D.H., 2018, Provenance analysis of the Ochoco basin, central Oregon: A window into the Late Cretaceous paleogeography of the northern U.S. Cordillera, *in* Ingersoll, R.V., Graham, S.A., Lawton, T.F. (eds.), Tectonics, Sedimentary Basins, and Provenance: A Celebration of William R. Dickinson's Career: Geological Society of America Special Paper 540, 235-266, https://doi.org/10.1130/2018.2540(11).
Taliaferro, N.L., 1933, An occurrence of Upper Cretaceous sediments in northern Sonora, Mexico: Journal of Geology, 41, 12-37.
Tappan, H., 1940, Foraminifera from the Grayson Formation of northern Texas: Journal of Paleontology 14, 93-126.
Valencia-Moreno, M.A., González-León, C.M., Solari, L., Rascón-Heimphel, M., González-Becuar, E., Lozano-Santacruz, R., Pérez-Arvizu, O., 2023, U-Pb zircon geochronology and geochemistry of the Jurassic magmatic rocks from the region of Cananea and Nacozari, northeastern Sonora, Mexico: timing and composition of the southernmost edge of the Jurassic Cordilleran arc: Canadian Journal of Earth Sciences, https://doi.org/10.1139/cjes-2023-0059.
Vermeesch, P., 2012, On the visualisation of detrital age distributions: Chemical Geology, 312-313, 190-194, doi: 10.1016/j.chemgeo.2012.04.021.
Vermeesch, P., 2018, IsoplotR: a free and open toolbox for geochronology: Geoscience Frontiers, 9, 1479-1493, doi: 10.1016/j.gsf.2018.04.001.
White, C.A., 1890, Descriptions of new Cretaceous invertebrate fossils from Kansas and Texas: U.S. National Museum Proceedings, 2, 292-298.
Wiedenbeck, M., Allé, P., Corfu, F., Griffin, W.L., Meier, M., Oberli, F., Von Quadt, A., Roddick, J., Spiegel, W., 1995, Three natural zircon standards for U-Th-Pb, Lu-Hf, Trace element and REE Analyses: Geostandards Newsletter, 19, 1-23, https://doi.org/10.1111/j.1751-908X.1995.tb00147.x.

Manuscript received: June 27, 2023
Corrected manuscript received: September 8, 2023
Manuscript accepted: September 11, 2023