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The first geologic map of Sonora

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Abstract

The 1888 publication by José Guadalupe Aguilera Serrano about the 3 May 1887 Sonora, Mexico earthquake contains the earliest geologic map of Sonora, a 1:1,000,000 scale color map with six cartographic units, reproduced in this paper. On the map, which covers ~20,000 km^2 of northeastern Sonora, and in the accompanying article, Aguilera delimited and described parts of what is now known as the Jaralito and Oposura batholiths and assigned them, remarkably, an Eocene age. The map unit of volcanic rocks belongs mostly to the vast cover of the middle Tertiary Sierra Madre Occidental volcanic province and the units of Pliocene and Quaternary rocks to the fill of extensional basins. Aguilera assigned a Quaternary age to the basalt flows in the Moctezuma and San Bernardino valleys, which he described as covering the alluvium of these valleys. The rocks of the Pliocene map unit were described by Aguilera as an indurated conglomerate dipping 20° S, overlain with angular unconformity by alluvium, and most of its clasts being of volcanic origin; this unit is now known as the Báucarit Formation of Miocene age. The Cretaceous map unit, described by Aguilera as ash grey, compact, and fossiliferous limestone beds belonging very probably to the Comanche series, is now known as the Lower Cretaceous Mural Limestone. Aguilera's map covers a series of north-south trending mountain ranges separated by the Moctezuma, Bavispe, San Bernardino, Fronteras, and Agua Prieta River valleys, a landscape pattern typical of the Basin and Range physiographic province. Aguilera described this transition zone between the plateau of the Sierra Madre Occidental in the east and the lowlands in the west as a large-scale staircase pattern, with the steep, fault-bounded side of the mountain ranges always facing west. A rare photograph by Camillus S. Fly possibly shows Aguilera and his field party near Bavispe, Sonora in August 1887.

Key words: José Guadalupe Aguilera Serrano [1857-1941], history of geology, geologic map, Sonora, Mexico, Basin and Range province, Sonoran batholith

Resumen

La publicación en 1888 por José Guadalupe Aguilera Serrano sobre el terremoto del 3 de mayo de 1887 de Sonora incluye la primera carta geológica de Sonora. Se trata de un mapa en color a escala 1:1,000,000 con seis unidades cartográficas, el cual es reproducido en este trabajo. En el mapa, que cubre ~20,000 km^2 del noreste de Sonora, y en el artículo que acompaña al mapa, Aguilera delimitó y describió partes de lo que se conoce actualmente como los batolitos de Jaralito y de Oposura y les asignó notablemente una edad eocena. La unidad cartográfica de rocas volcánicas pertenece sobre todo a la cobertura amplia de la provincia volcánica de la Sierra Madre Occidental del Terciario medio y las unidades de rocas del Plioceno y Cuaternario al relleno de cuencas de extensión. Aguilera asignó una edad cuaternaria a los derrames de basalto en los valles de Moctezuma y San Bernardino y los describió como cubriendo al aluvión de estos valles. A las rocas de la unidad cartográfica pliocénica, Aguilera las describió como conglomerado bastante resistente con echado de 20° S, cubierto con discordancia angular por aluvión, y con la mayoría de los clastos siendo de origen

volcánico. Esta unidad se conoce ahora como Formación Báucarit de edad miocena. La unidad cartográfica del Cretácico, descrito por Aguilera como capas de caliza gris cenicienta compacta y fosilífera, perteneciendo muy probablemente a la serie Comanche, se conoce ahora como la Caliza Mural del Cretácico Inferior. El mapa de Aguilera cubre una serie de valles de orientación norte-sur separados por los valles de los Ríos Moctezuma, Bavispe, San Bernardino, Fronteras y Agua Prieta, lo que es el patrón de paisaje típico de la provincia fisiográfica de cuencas y sierras. Aguilera describió esta zona de transición entre el plateau de la Sierra Madre Occidental al oriente y la tierra baja al poniente como una gigantesca escalinata formada por diversas cordilleras, cuya mayor pendiente ve siempre hacia el oeste. Una fotografía rara por Camillus S. Fly posiblemente muestra a Aguilera con su equipo de campo cerca de Bavispe, Sonora en agosto de 1887.

Palabras clave: José Guadalupe Aguilera Serrano [1857-1941], historia de la geología, carta geológica, Sonora, México, provincia de cuencas y sierras, batolito de Sonora

1. Introduction

The purpose of this short note is to highlight the geologic map (Figure 1) that is part of the outstanding study José Guadalupe Aguilera Serrano [1857-1941] made of the devastating 3 May 1887 M_w 7.5 Sonora earthquake. Aguilera's 1888 publication (in Spanish), which is based on his expedition to the epicentral region of this earthquake in the summer of 1887, is an important contribution to the regional geology and seismology of Mexico. Beside the first geologic map of northeastern Sonora (published in color), it includes a detailed surface rupture map and the earliest isoseismal map, source parameters, and seismic velocities of an earthquake in Mexico. Nevertheless, Aguilera's study is not widely known today, and he is not given credit for his pioneering achievements in reviews of the history of seismology (for example, Davison, 1927; Agnew, 2002) or earthquake geology (historical vignettes in Yeats *et al.*, 1997). Here, I focus on Aguilera's geologic map; elsewhere (Suter, 2006), I reviewed the major seismologic accomplishments in Aguilera's study of the 1887 earthquake and placed them in a historical context.

2. Aguilera's expedition

Aguilera was dispatched to the epicentral region on 1 July 1887 from Hermosillo, Sonora (Figure 1), where he was employed by the Scientific Commission of Sonora (*Comisión Científica de Sonora*) as Head of the Department of Naturalists (*Jefe de la Sección Naturalista*). In his work order, which is included in his 1888 publication on page 9, he was asked not only to study the earthquake but also to describe the regional geology along his itinerary, collect rock samples, and construct a geologic map and cross sections. Aguilera was accompanied by a military crew carrying out triangulation that resulted in a topographic map of the expedition area. In Aguilera's 1888 report, credit for the topographic work is given to Juan B. Laurencio and Nicolás Lazo de la Vega, who possibly are depicted in Figure 2.

The itinerary of the expedition, ~750 km long, is marked on the geologic (Figure 1) and topographic maps in Aguilera's 1888 report. The field party traveled from Hermosillo to Moctezuma and from there to Bavispe, where they spent 15 days in August 1887 documenting the damage to the village and mapping ground fissures (Aguilera, 1888, p. 37). From Bavispe, they moved to the junction of the Bavispe and San Bernardino Rivers (Figure 1) and mapped the earthquake surface rupture scarp that passes along the eastern margin of the San Bernardino valley (now known as Pitáycachi segment of the 1887 rupture; Suter, 2001; Suter and Contreras, 2002). The expedition then proceeded on the U.S. side of the international boundary from San Bernardino (Figure 1) to Agua Prieta, from where they returned to Moctezuma and Hermosillo.

In Bavispe, Aguilera met in August 1887 Dr. George Emory Goodfellow [1855-1910] (Chaput, 1996), a physician and naturalist from Tombstone, Arizona Territory, who was also involved in an observational study of the 1887 earthquake (Goodfellow, 1887a, 1887b, 1888) together with the photographer Camillus Sidney Fly [1849-1901] (Vaughan, 1989; Cooper, 1989; Rowe, 1997). Goodfellow's (1887b) study includes the first surface rupture map of an earthquake in North America, and Fly's photographs are the earliest photographs worldwide of an earthquake rupture scarp. Goodfellow's map and several of Fly's photographs of the surface rupture were reproduced in Suter (2006, figs. 3 and 6-10) and his photographs of the earthquake damage in Bavispe in DuBois and Smith (1980, figs. 12-15). The encounter between Goodfellow and Aguilera is mentioned by Goodfellow (1888, p. 162). A group portrait taken by Fly near Bavispe, at a place where major fissures developed in the flood plain of the Bavispe River, possibly shows the two field parties (Figure 2). A print of this photograph in the Steinbrugge Collection (University of California, Berkeley) includes the caption "Depressions or seismic troughs in river bed. View from Babispe, looking northwest. (Fly)" A comparison with photographs in Chaput (1996) suggests that the person labeled G is very likely Goodfellow, who was 32 years of age when this picture was taken. Based on a comparison with a picture in de Cserna (1990, fig. 14) and Gómez-Caballero (2005, fig. 9), Aguilera is possibly the person labeled A. Aguilera was the only civilian in the Mexican field party and 30 years old at the time the picture was taken. The second

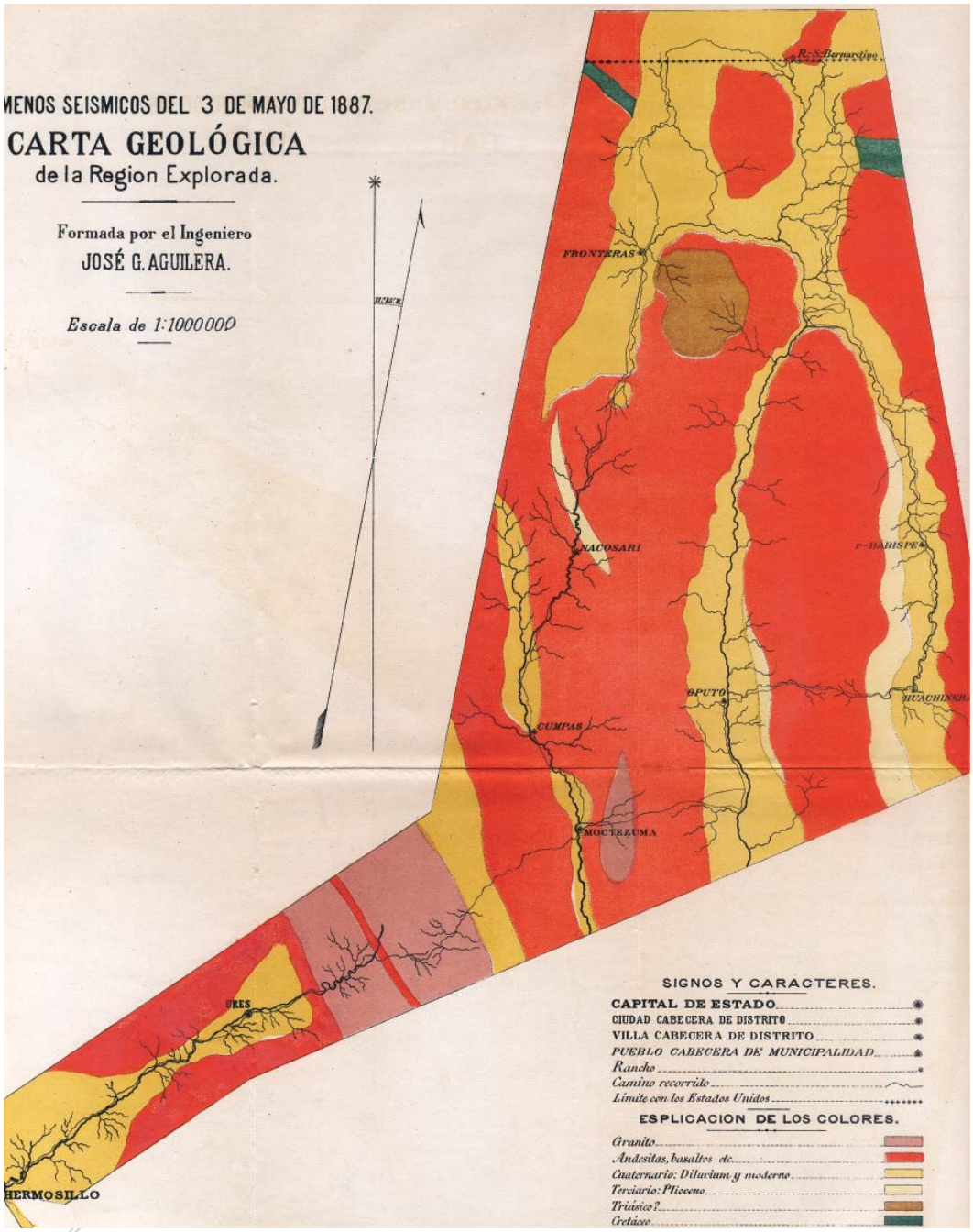

Figure 1. Excerpt from the geologic map of northeastern Sonora by José G. Aguilera (1888). The original map scale is 1: 1,000,000. The reproduction is reduced to a scale of ~1: 1,500,000. The map employs six cartographic units and shows Aguilera's itinerary.

person from the right (labeled L) is possibly Major Juan B. Laurencio, topographer of the Aguilera expedition. Based on comparisons with photographs in Smith (1970) and Truett (2004), the civilian on the outer right (labeled K) is likely to be Emilio Kosterlitzky [1853-1928], a German-Russian immigrant who worked in 1887 in Bavispe for the Mexican customs guard or *Gendarmería Fiscal*, and who registered the aftershocks of the 3 May 1887 earthquake (Orozco y Berra, 1888, p. 522).

3. Aguilera's geologic map of northeastern Sonora

Aguilera published the results of his expedition in 1888; the preface to his article was written in Hermosillo on 18 March 1888. The first half of his article is taken up by the geologic description of his itinerary and the collected samples, whereas the second half is related to the 3 May 1887 earthquake. The article includes four plates: an iso-seismal map (scale: 1:6,000,000) covering the southwestern

US and Mexico; a geologic map of northeastern Sonora (scale: 1:1,000,000); a topographic map of northeastern Sonora (scale: 1:1,000,000; contour interval: 250 m) that shows the surface rupture and ground fissures caused by the earthquake; and a plate with five geologic cross sections. The isoseismal map and the part of the topographic map showing the earthquake surface rupture are reproduced in Suter (2006, figs. 5 and 11). Aguilera (1888, p. 7) considered the topographic and geologic maps necessary tools to document and interpret the earthquake-related field observations and to formulate a hypothesis about the cause of the earthquake.

Aguilera's 1:1,000,000 scale geologic map is reproduced here on a reduced scale (~1:1,500,000) as Figure 1. This is likely to be the earliest geologic map covering a part of Sonora. Aguilera's map is little known to geologists working in Sonora today; it has barely been referenced in recent work about this region. The map reaches from Hermosillo in the southwest to the boundary with the United States and Chihuahua in the northeast and covers an area of ~20,000 km². Aguilera employed six cartographic units: granite; volcanic rocks; Quaternary rocks; Pliocene rocks; Cretaceous rocks; and an outcrop of questionable Triassic age southeast of Fronteras (Figure 1).

The granite unit on Aguilera's map includes two outcrops. The western one, east of Ures, is now known as the granitic-granodioritic Jaralito batholith and has a radiometric age between 51.8 and 69.6 Ma (Anderson *et al.*, 1980; Roldán-Quintana, 1991). The eastern outcrop, east of Moctezuma (Figure 1), now known as the Oposura batholith, has a granitic-granodioritic-quartz monzonitic composition and a radiometric age between 59 and 62 Ma (Roldán-Quintana, 1994). These rocks belong to the Sonoran batholith, which is part of the subduction-related Late Cretaceous – early Tertiary (Laramide) magmatic arc (McDowell *et al.*, 2001). Based on its contact, Aguilera inferred this granite to be older than the overlying rocks of the Sierra Madre Occidental volcanic province and assigned it, remarkably, an Eocene age (Aguilera, 1888, p. 26), over 100 years before this age was confirmed by radiometric studies.

Aguilera's unit of volcanic rocks belongs mostly to the vast cover of the middle Tertiary Sierra Madre Occidental volcanic province and his units of Pliocene and Quaternary rocks to the fill of extensional basins. These units define on his map a series of north-south trending fault-bounded mountain ranges separated by the valleys of the Sonora, Moctezuma, Bavispe, Fronteras, San Bernardino and Agua Prieta rivers (Figure 1), a landscape pattern typical of the southern Basin and Range physiographic province (Parson, 1995). Aguilera (1888, p. 12) describes this transition zone between the plateau of the Sierra Madre Occidental in the east and the lowlands in the west as a gigantic staircase pattern, with the steep, fault-bounded side of the mountain ranges always facing west.

Aguilera (1888, p. 13, 21, and 30) assigned a Quaternary age to the basalt flows in the Moctezuma (Paz Moreno *et al.*, 2003) and San Bernardino (Gerónimo volcanic field; Kempton and Dungan, 1989; Biggs *et al.*, 1999) valleys, which he described as covering the alluvial fill of these valleys. The rocks of the Pliocene map unit are described by Aguilera (1888, p. 15) between Huásabas and Óputo (now Villa Hidalgo) as an indurated, 20° S dipping conglomerate, with most of its clasts being of volcanic origin, and local concentrations of gypsum, overlain with angular unconformity by alluvium. This unit is now known as the Báucarit Formation of Miocene age (Bartolini *et al.*, 1994; McDowell *et al.*, 1997).

The Cretaceous map unit is represented by two outcrops east of the San Bernardino River valley and west of the Agua Prieta River valley (Figure 1). The western one of these outcrops, which is crossed by the international boundary west of Agua Prieta (Figure 1), has a NW-SE orientation resulting from Laramide shortening (Warzeski (1987). Aguilera (1888, p. 20-21) refers to these rocks as ash grey, compact, and fossiliferous limestone belonging very probably to the Comanche. The marine limestone mapped by Aguilera, now known as the Lower Cretaceous Mural Limestone of the Bisbee Group, was studied in detail by Warzeski (1987), who erroneously credits Dumble (1900) for having first reported these rocks. Aguilera's map also contains a Triassic unit shown southeast of Fronteras (Figure 1). However, Aguilera did not describe these rocks in the text, and the outcrop was not included in the 1889 geologic map of Mexico (de Cserna, 1990, pl. 1).

Furthermore, Aguilera (1888, p. 20) describes a 60 m section of lake deposits east of Batepito, probably in the lowermost part of Arroyo de la Cabellera (located on Figure 1 northeast of the junction of the Bavispe and San Bernardino Rivers, where Aguilera's itinerary doubles back) composed of thin bedded alternations of marl and chert-bearing limestone, and compares them to the lake deposits of the Mexico City basin (profile at Tajo de Nochistongo). Aguilera (1888, p. 22) also reports rocks of similar lithology near Cabullona, now known as deposits of the Cabullona basin (González-León and Lawton, 1995), which he correlates with the lake deposits he observed near Batepito.

4. Discussion

Additionally to his employment with the Scientific Commission of Sonora, Aguilera also held a position as *Segundo Naturalista* at the *Comisión Geográfico-Exploradora*, the Mexican federal mapping agency of its time, with headquarters in Jalapa, Veracruz (Rubinovich Kogan *et al.*, 1991). It is likely that Aguilera was assigned to the Scientific Commission of Sonora not because of the earthquake but to do field mapping for the first geologic map of the Republic of Mexico (1:3,000,000 scale), which was published in 1889 (facsimile in de Cserna, 1990, pl.

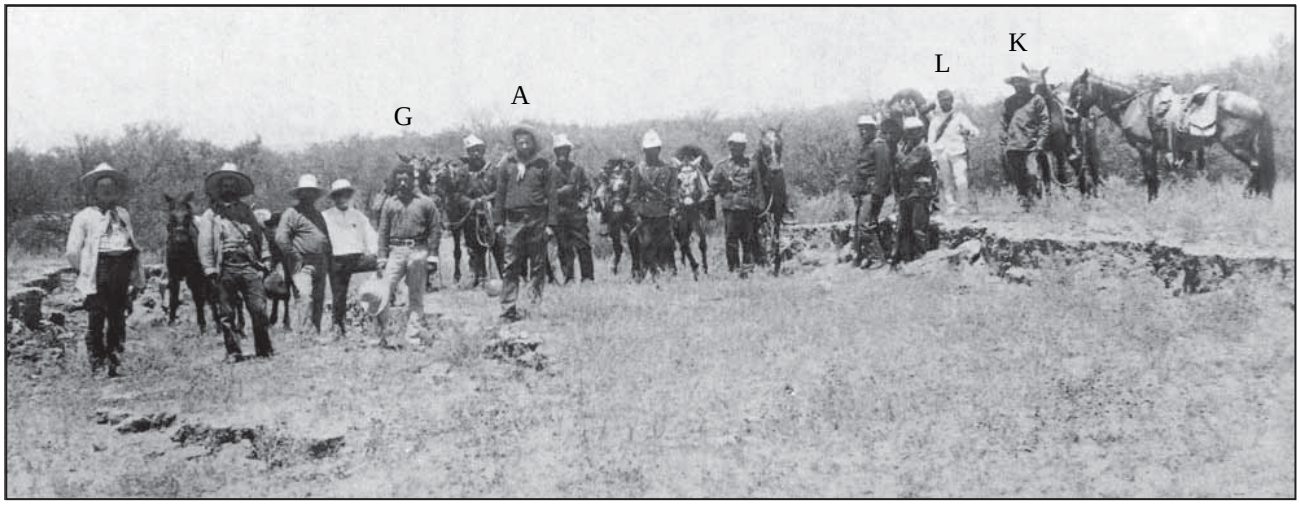

Figure 2. Photograph by Camillus S. Fly possibly showing José G. Aguilera and his field party in August 1887 near Bavispe, at a place where major fissures formed a small graben in the flood plain of the Bavispe River. The labeled persons are interpreted to be G: Dr. George E. Goodfellow, a physician and naturalist from Tombstone, Arizona Territory, who was also involved in an observational study of the 1887 earthquake; A: José G. Aguilera; L: Major Juan B. Laurencio, topographer of the Aguilera expedition; and K: Emilio Kosterlitzky.

1). This map was based on geologic reconnaissance trips he had taken in Sonora not only to the epicentral region of the 1887 earthquake, but also among other places to San Javier and to Sahuaripa, Arivechi, and Cerro de las Conchas in eastern Sonora (Aguilera and Ordóñez, 1897). The 1889 geologic map of Mexico shows, additionally to the information on Aguilera's 1888 map and among other things the Cretaceous limestone outcrops at Lampazos and in the surroundings of Sahuaripa, as well as more extended outcrops of the Sonoran batholith and the Sierra Madre Occidental volcanic province.

Aguilera's 1888 paper does not contain bibliographical references, which were still not customary at that time. It is for that reason difficult to reconstruct what geologic information was available to him about the study area. The closest Aguilera comes to making a reference is his mentioning that the Comanche series was "recently established by the distinguished paleontologist of the U.S. Geological Survey, Dr. C.A. White, in his exploration of the Cretaceous in the southern and southwestern United States" (Aguilera, 1888, p. 21). Darton's 1896 index to North American geology and Aguilar y Santillán's 1898 bibliography of Mexican geology provide clues about what was known in 1887 about the geology of northeastern Sonora; it is a dearth of information that includes the survey of the international boundary region by Emory (1859) and a compilation by Marcou (1867). None of the references contains a geologic map of Sonora; neither does the catalog of geologic maps of America by Marcou and Marcou (1884, updated 1893) indicate any map that would cover Sonora. The geologic map of the Emory survey does not provide relevant information about Sonora, and the geologic map sheet of the Wheeler Survey covering southeastern Arizona and southwestern New Mexico (Gilbert *et al.*, 1877) only reaches as far south as the northern part of the Chiricahua Mountains (Gilbert, 1875), ~90 km north of the international boundary. Aguilera's 1888 map (Figure 1) ranks therefore as the earliest geologic map of Sonora.

5. Conclusions

The 1888 publication by José Guadalupe Aguilera Serrano about the 1887 Sonora, Mexico earthquake includes the earliest geologic map of Sonora, a 1:1,000,000 scale color map with six cartographic units covering ~20,000 km² of northeastern Sonora. The map and the accompanying article signified major advancements in the regional geology of northeastern Sonora. The transition zone between the plateau of the Sierra Madre Occidental in the east and the lowlands in the west was recognized as a large-scale staircase pattern, with the steep, fault-bounded side of the mountain ranges always facing west. A map pattern typical of the Basin and Range physiographic province is defined by north-south trending mountain ranges separated by major river valleys; on Aguilera's map the fault-bounded mountain ranges exhibit volcanic rocks of the Tertiary Sierra Madre Occidental volcanic province, whereas the intervening extensional basins are filled with siliciclastic rocks of the Pliocene and Quaternary map units. The basalt flows in the Moctezuma and San Bernardino valleys were described as covering the alluvial fill of these valleys and were assigned a Quaternary age. The Pliocene map unit (now known as the Miocene Báucarit Formation) was described as overlain by alluvium with an angular unconformity. Lake deposits composed of sandstone and thin bedded alternations of marl and chert-bearing limestone were described from near Cabullona and Batepito.

The Jaralito and Oposura batholiths were recognized to be older than the rocks of the Sierra Madre Occidental volcanic province and were assigned an Eocene age. A northwest-southeast oriented outcrop of the Cretaceous unit was mapped across the international boundary west of Agua Prieta and described as ash grey, compact, and fossiliferous limestone (now known as the Lower Cretaceous Mural Limestone of the Bisbee Group).

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